Strategic and Critical Materials 2015 Report on Stockpile Requirements

Under Secretary of Defense for Acquisition, Technology and Logistics

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Executive Summary

Introduction

The primary purpose of the National Defense Stockpile (NDS Program) is to decrease the risk of dependence on foreign suppliers or single suppliers on supply chains of strategic and critical materials used in defense, essential civilian, and essential industry applications. The NDS Program allows for decreasing risk by maintaining a domestically held inventory of necessary materials.

Under Section 14 of the Stock Piling Act, the Secretary of Defense must submit a report on stockpile requirements to Congress by January 15th of every other year. The report must include stockpile requirements and detail the key supply-demand assumptions used in arriving at its recommendations.

The United States' industrial base depends upon global supply chains that are becoming increasingly complex. In general, globalization results in lower costs, more efficient supply chains, and access to more resources. However, globalization creates a dependency on foreign sources of minerals, materials, and, finished goods.

This dependency is growing. According to the United States Geological Survey (USGS), in 1999 the United States was at least 50 percent dependent on a foreign source for 27 out of the 100 materials covered in its publication *Mineral Commodity Summaries*. By 2013, this number had grown to 41 materials out of 100. Many of these materials are essential to the defense, technology and energy sectors. For example, the United States' import reliance on tantalum is 100 percent, gallium 99 percent, titanium 79 percent, and cobalt 76 percent according to the USGS 2014 *Mineral Commodity Summaries*.

Materials with Approved Acquisition Authority

Defense Logistics Agency Strategic Materials received authorization in Section 1412 of the Fiscal Year (FY) 2014 National Defense Authorization Act (NDAA) to acquire six materials in order to mitigate their supply chain risk. Results from the 2013 Requirements Report research formed the basis of support for these authorizations. Congress has allocated approximately $41 million from the NDS Program Transaction Fund (T-Fund) to purchase the materials.

They are

- ferroniobium,
- dysprosium metal,
- yttrium oxide (including high purity yttrium oxide),
- cadmium-zinc-tellurium substrate materials,
- lithium-ion precursors, and
- triamino-trinitrobenzene and insensitive high-explosive molding powders.

Studied Materials

For this report, the NDS Program implemented a repeatable method for identifying strategic and critical materials. The NDS Program monitors over 160 minerals and processed materials on a "Watch List" created and updated with input from industry stakeholders and key government agencies. Of these 160 materials, 92 meet at least one of a set of vulnerability metrics grouped as follows:

- 68 "standard" materials for which the full suite of models known as the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) was used;
- 11 "non-standard proprietary" materials, for which portions of the RAMF-SM models were used;
- 13 "bottom up" materials analyzed by supply-chain analysis methods.

A complete list of the materials can be found in Appendix 2a.

It should be noted that downstream forms and multiple grades were assessed for several materials. The reader is referred to Appendix 2a and proprietary Appendices 2h and 6b for further details.

NDS Program research identified net shortfalls for 21 materials. Requested actions and recommendations for stockpiling are based on net shortfall amounts. These are discussed in Chapter 1.

Materials Requested for Action

The NDS Program has already proposed actions regarding nine of the 21 materials exhibiting a net shortfall. These requests are based on the results of either the 2013 or analyses conducted in support of this 2015 Requirements Report. The requests for action on these materials are in various stages of approval and are presented in Chapter 1. In alphabetical order they are

- boron carbide,
- carbon fiber (five types),
- germanium,
- tantalum, and
- tungsten-rhenium ingot.

Materials Recommended for Stockpiling

Section 12 (1) of the Stock Piling Act defines strategic and critical materials as materials that (A) would be needed to supply the military, industrial, and essential civilian needs of the United States during a national emergency and (B) are not found or produced in the United States in sufficient quantities to meet such need. Based on the results of the 2015 Requirements Report research, the NDS Program recommends new authorities for twelve of the 21 materials exhibiting a net shortfall. In alphabetical order they are

- aluminum oxide, fused crude,
- antimony,
- beryllium metal,
- carbon fiber (two types),
- chlorosulfonated polyethylene,
- europium,
- germanium,
- lanthanum,
- magnesium,
- manganese metal, electrolytic, and,
- silicon carbide fiber, multifilament.

Alternative Mobilization Periods

Section 14b of the Stock Piling Act mandates the Secretary shall base the national emergency planning assumptions on a military conflict scenario consistent with the scenario used by the Secretary in budgeting and defense planning purposes. Section 14d of the act further mandates inclusion of … "the effects of alternative mobilization periods and other military conflict scenarios on the recommendations".

Specifically, the law mandates that the Department of Defense (DoD) conduct analysis of alternative cases that incorporate more stressful assumptions about the nature and duration of the national emergency, international environment, and U.S. response. Chapter 3 of this report examines several different alternative cases including the Closed Economy case described in Chapter 3.4.

Table 1 summarizes the gross shortfalls (shortfalls prior to anticipated market-based responses by private industry) for each alternate case and the closed economy case.

Table 1: Gross Shortfalls for Alternate (Alt) Cases and Closed Economy (CE) Case

	Base Case	Alt I	Alt II	Alt III	Alt IV	CE
Number of materials in gross shortfall	30 out of 92	24 out of 68	24 out of 68	24 out of 68	24 out of 68	48 out of 68
Value (million)	\$3,183	\$3,694	\$3,657	\$3,594	\$3,557	\$29,142

Note: The Alternate Cases and Close Economy scenarios were modeled without consideration of domestic single points of failure and only considered 68 materials that met the minimal data requirements for RAMF-SM.

Structure of the Report

The Strategic and Critical Materials 2015 Report on Stockpile Requirements follows the structure of Section 14a of the Stock Piling Act. The main report consists of four parts: Recommendations; National Emergency Planning Assumptions; Recommendations under Alternative Mobilization Periods and Conflict Scenarios; and, Plans of the Stockpile Manager.

Part 1: The Secretary's Recommendations for the National Defense Stockpile

Chapter 1.1 Materials Recommended for Stockpiling

This 2015 Report on Stockpile Requirements identifies net shortfalls under Base Case conditions and/or single points of failure for 21 materials of the 85 materials identified as vulnerable to a shortfall. The shortfalls were generated by one of the following research processes: a top-down methodology; a bottom up methodology; or, extensive supply chain research conducted in response to requests from the Congress, the Department of Defense (DoD) or military services.

A description of these materials' major defense applications, supply conditions and, net import reliance is provided in Table 1.1.1 below.

Table 1.1.1: Overview of Materials Identified to Be in Net Shortfall

Material	Key Defense Applications	Supply Conditions	U.S. Net Import Reliance (percent of demand)
Aluminum oxide, fused crude	Abrasive/milling products, clay building materials, refractories manufacturing, soaps and cleaners.	Foreign reliance; U.S. imports from China and Venezuela.	100 percent
Antimony	Military lead-acid batteries, indium antimonide semiconductors for FLIR systems and IR missiles, fuses, small arms ammunition, mortar rounds, artillery projectiles, and flame resistant textiles and plastics.	No U.S. mine, single U.S. smelter. U.S. imports from China and Mexico.	85 percent
Beryllium metal	ISR guidance systems, chassis and support arm/beam components, neutron reflectors and X-ray mirrors.	Withheld (W)[1]	Net exporter
Boron carbide	Ceramic body armor plate, aircraft and ship armor panels.	W	W

[1] Data designated as proprietary, classified or sensitive is withheld and may be found in the proprietary or classified appendices as appropriate.

Table 1.1.1: Overview of Materials Identified to Be in Net Shortfall (continued)

Material	Key Defense Applications	Supply Conditions	U.S. Net Import Reliance (percent of demand)
Carbon Fiber (Seven types) (1)	Rocket motors, missiles, pressure vessels, manned and unmanned military aircraft, helicopters blades, commercial space launch vehicles, and satellites.	W	W
Chlorosulfonated polyethylene (CSM, a type of synthetic rubber)	Tires, hoses, lining for clothing.	Foreign reliance; U.S. imports from Japan and China.	100 percent
Europium	Phosphors, polishing powders, and ceramics.	Minimal U.S. production.	>90 percent
Germanium	Fiber optics, infrared optics, polymerization catalysts, electronics and solar cells. Key defense applications include missile guidance and solar cells for satellites.	Minimal U.S. production.	85 percent
Lanthanum	NiMH batteries and fluid cracking catalysts.	The U.S. has one producer.	74 percent
Magnesium	Helicopter transmission housings, armor applications, broadcast and wireless communication equipment, radar equipment, torpedoes, anti-tank ammunition rounds, batteries, flare and ordinance applications, and infrared and missile countermeasures.	Single point of failure.	25 percent

Table 1.1.1: Overview of Materials Identified to Be in Net Shortfall (continued)

Material	Key Defense Applications	Supply Conditions	U.S. Net Import Reliance (percent of demand)
Manganese metal, electrolytic	Steel alloys, aluminum alloys, and super alloys.	Foreign reliance; U.S. imports from China and South Africa.	100 percent
Silicon carbide fiber, multifilament	Reinforcement of plastic and ceramic composites mainly for aerospace and missile defense.	Minimal U.S. production.	>90 percent
Tungsten ores and concentrates	High-temperature superalloys used in military turbine engines, tungsten filaments for electronics and lighting and armor-piercing ammunition are key defense uses.	Single U.S. mine and other possible single points of failure along supply chain. Most tungsten worldwide is mined and refined in China.	40 percent
Tungsten-rhenium (W-Re) alloy	Military turbine engines; filaments for electronics and lighting; microwave tubes for radar technologies.	Foreign reliance; sole U.S. manufacturer exited tungsten-rhenium wire business in 2013.	100 percent for W-Re wire
Yttrium oxide, high purity	W	Foreign reliance	100 percent

(1) A request for action for five types of carbon fiber is pending. In the FY2015 Requirements Report, the NDS Program is recommending acquisition of two additional types of carbon fiber, bringing the total acquisition to seven types.

Based on recent prior editions of the Requirements Report as well as other previous research, the National Defense Stockpile (NDS Program) Program has already requested approval to stockpile nine of these 21 materials. These nine materials are: boron carbide, carbon fiber (five types), germanium, tantalum, and tungsten-rhenium ingot. The nine materials requested for stockpiling are summarized in Table 1.1.2 below.

Table1.1.2: Materials Already Requested for Stockpiling

Material	Reason for Shortfall	Requested Action
Boron carbide	Foreign market dominator.	Stockpile ceramic-grade boron carbide; quantity withheld.
Carbon fiber (five types)	Import reliance.	Stockpile five types; quantity withheld.
Germanium	Single point of failure; high import reliance.	Stockpile 6,346 kilograms.
Tantalum	Import reliance; conflict mineral.	Stockpile an additional 187,000 pounds tantalum.
Tungsten-rhenium ingot	Single point of failure.	Stockpile 5,000 kilograms of tungsten-rhenium alloy ingot.

In addition to the pending actions on the nine materials mentioned above, the NDS Program is recommending twelve new materials for stockpiling in this Report. Table 1.1.3 summarizes these recommendations and provides a rationale for the net shortfall.

Table1.1.3. Materials Recommended for Stockpiling

Material	Reason for Shortfall	Recommended Action
Aluminum oxide, fused crude	High import reliance.	Legislative authority to purchase up to the shortfall amount of 18,268 short tons.
Antimony	Single point of failure and high import reliance.	Legislative authority to purchase up to the shortfall amount of 13,118 short tons.
Beryllium metal	Single point of failure.	W
Carbon fiber (two types)	Import reliance.	Legislative authority to purchase up to the shortfall amount.

Table 1.1.3 Materials Recommended for Stockpiling (continued)

Material	Reason for Shortfall	Recommended Action
Chlorosulfonated polyethylene	High import reliance.	Legislative authority to purchase up to the shortfall amount of 216 metric tons.
Europium	High import reliance; single point of failure.	Legislative authority to purchase up to the shortfall amount of 37 metric tons oxide.
Germanium	High import reliance.	Legislative authority to purchase up to the shortfall amount of an additional 10,000 kilograms of germanium metal.
Lanthanum	High import reliance; single point of failure.	Legislative authority to purchase up to the shortfall amount of 820 metric tons oxide.
Magnesium	Single point of failure.	Legislative authority to purchase up to the shortfall amount of 5,422 metric tons.
Manganese metal, electrolytic	High import reliance.	Legislative authority to purchase up to the shortfall amount of 1,480 short tons.
Silicon carbide fiber, multifilament	High import reliance.	Legislative authority to purchase up to the shortfall amount.

Chapter 1.2 Shortfall Estimation

Introduction

Defense Logistics Agency – Strategic Materials analysts calculated the shortfalls in this report using two methods. The first is a "top-down" method. This method calculates shortfalls from a large collection of economic data using formal econometric models that are described below. Previous requirements analyses used this method exclusively. The second is a "bottom-up" method and is used when the demand and supply data is insufficient for formal econometric modeling or when the top-down method was unable to pick up supply chain issues. The following provides detailed descriptions of each method.

Top-Down Methodology

The top-down economic method utilizes a process named the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM). RAMF-SM consists of a suite of modeling and simulation tools developed by the Institute for Defense Analyses (IDA) and the University of Maryland Inter-industry Forecasting Project (INFORUM). The process determines if the nation may experience material shortfalls in the event that a national emergency occurs.

Four models and simulations are used to conduct strategic and critical material supply modeling. The Long-term Inter-industry Forecasting Tool (LIFT) and Inter-industry Large-scale Integrated and Dynamic (Iliad) models are from INFORUM. These economic input/output models forecast civilian industrial demand, base military demand, and industrial supply. The Forces Mobilization Model (FORCEMOB) computes the extraordinary military demand for combat weapons, munitions, and combat support material. These calculations produce material demands to accommodate the extra military demand for the national emergency being modeled.

The Stockpile Sizing Module (SSM) then compares material supplies against material demands. The difference is the gross shortfall. For the materials that exhibit a gross shortfall, the model considers possible mitigation actions from the private sector that could offset either all or part of the gross shortfall. Materials are in net shortfall when actions by the private sector are insufficient to offset the entire gross shortfall. Further details of these methods are contained in Chapter 2 and Appendix 2.

Bottom-Up Methodology

The Bottom-Up method evaluates potential shortfalls by conducting fundamental research using primary sources. The NDS Program uses this method when it has access to some demand and supply data but lacks the specificity needed for formal econometric modeling or to detect supply chain issues. The Bottom-Up method is usually applicable for semi-processed materials or for materials that are proprietary to a single company and qualified for defense platforms.

NDS Program analysts build demand projections using data that are as specific as possible to the final application for the material. Often, this involves interviews with customers, military services program managers and weapons system forecasts. Analysts base supply projections upon an in-depth analysis of an entire supply chain. NDS Program analysts move from one end of the supply chain to the other, stopping at each node to probe for potential risks. Potential risks include lack of domestic capacity, unreliability of domestic capacity, concentration of foreign capacity in the hands of potentially unfriendly nations, and competition with other nations for scarce resources. NDS Program analysts combine production capacity estimates with demand projections to produce shortfall estimates under a conflict scenario.

Summary of Shortfall Materials

As mandated by the Stock Piling Act, Section 14b, the NDS Program models a national emergency scenario "consistent with the scenario used by the Secretary in budgeting and defense planning purposes." This report refers to this set of national emergency planning assumptions as the "Base Case." The NDS Program modeled supply and demand for materials under Base Case assumptions. This determined which materials might have insufficient supplies to meet defense, essential civilian and, industrial needs during a national emergency.

The model generated two types of shortfall: gross and net. Gross shortfalls are simply supply minus demand, whereas net shortfalls account for anticipated actions by industry that would mitigate a portion of or the entire gross shortfall for some materials. Industry actions considered include substitution, thriftiness, and extra buys.

If market responses are insufficient to eliminate a shortfall, the government may act to close the gap. Authorities available to the government include the Defense Priorities and Allocation System (DPAS), Title III, Manufacturing Technology (ManTech) Program, and stockpiling. Consistent with Section 14 of the Stock Piling Act, this report focuses exclusively on stockpiling.

In past editions of this report, the Congress mandated that the NDS Program report on material shortfalls under the approved Base Case scenario within the context of the U.S.'s reliance upon foreign sources for strategic and critical materials. However, in Section 1412 of the FY 2013 NDAA, Section 2(b) of the Strategic and Critical Materials Stock Piling Act (50 U.S.C. 98 a (b)) was amended to also include an assessment of "single points of failure" in addition to foreign reliance.

In accordance with this recent revision to the Stock Piling Act, the model considers reliance on single points of failure in addition to foreign reliance. This report considered domestic single points of failure for beryllium, fluorspar, magnesium, and rare earth elements. Analyzing both foreign reliance and single points of failure resulted in 30 materials exhibiting a gross shortfall totaling $3.183 billion. Of these 30 materials, the top-down modeling method (RAMF-SM) identified gross shortfalls for 26 materials while the bottom-up method or other approaches found gross shortfalls for four additional materials. Of the 30 total materials exhibiting gross shortfalls, 21 have net shortfalls totaling approximately $389 million.

A subset of the materials evaluated have such a small supplier base that much of the data gathered is proprietary. In these instances, this report shows a “W,” for “Withheld”, in place of a numerical value. Withheld data is available in proprietary or classified appendices as appropriate.

Table 1.2.1: Shortfall Materials and Quantities

Number	Material	Gross Shortfall	Net Shortfall	Unit
1	Aluminum oxide, fused crude	281,441	18,268	short tons
2	Antimony	26,187	13,118	short tons
3	Beryllium metal	W	W	short tons
4	Borosilicate floated glass (one type)	7,575	0	metric tons
5	Boron carbide	W	W	metric tons
6 – 12	Carbon fiber (seven types)	W	W	metric tons
13	Chlorosulfonated polyethylene	1,271	216	metric tons
14	Dysprosium	7	0	metric tons oxide
15	Europium	65	37	metric tons oxide
16	Fluorspar, acid grade	117,779	0	short tons
17	Germanium	29,176	17,002	kilograms
18	Graphite	82,612	0	metric tons
19	Lanthanum	4,381	820	metric tons oxide
20	Magnesium	105,097	5,422	metric tons
21	Manganese metal, electrolytic	9,490	1,480	short tons

Table 1.2.1: Shortfall Materials and Quantities (continued)

Number	Material	Gross Shortfall	Net Shortfall	Unit
22	Rubber (natural)	555,653	0	long tons
23	Silicon carbide fiber, multifilament	W	W	short tons
24	Silicon carbide	28,495	0	short tons
25	Tantalum	33,990	0	pounds Ta
26	Tin	8,911	0	metric tons
27	Tungsten	26,581,064	4,116,169	pounds W
28	Tungsten-rhenium alloy	W	W	kilograms
29	Yttrium	26	0	metric tons oxide
30	Yttrium oxide	W	W	metric tons

Demand Assessment

Generating an estimate of demand for a material requires a comprehensive understanding of the material, its applications, and the factors that influence demand for each of its applications. To this end, NDS Program analysts ascertain what applications use the material, how demand for those applications is likely to change, potential uses for the material in new or different applications, and how price changes may affect demand. NDS Program analysts investigate the availability of substitutes for the downstream applications, and any disadvantages or difficulties in switching to these substitute(s). If demand for an application is tied to the performance of the domestic or global economy, then macroeconomic factors are considered as well.

NDS Program analysts rely heavily upon targeted research methods, especially interviews with material customers, distributors, systems integrators, industry experts, and scientific experts. IN addition, analysts obtain valuable information via collaboration with other Department of Defense (DoD) agencies. NDS Program analysts also make use of open source and proprietary databases that contain information on the material content of DoD parts.

Supply Assessment

A supply chain assessment of a particular material begins with a mapping of the entire supply chain. NDS Program analysts perform an in-depth investigation of each node of the supply chain, testing for weaknesses that may prevent the U.S. from obtaining the material in sufficient quantities during a conflict scenario.

NDS Program analysts examine whether demand for the material can be satisfied with current U.S. production. If so, NDS Program analysts investigate the health of the domestic supply base. NDS Program analysts pay special attention to the reliability and viability of single or sole sources of production. Variables such as the financial health, vulnerability to natural disasters or labor issues, level of exposure to DoD contracts and, their quality-control procedures are considered. NDS Program analysts also explore barriers to entry and consider how more firms could be encouraged to enter particular markets. Some of the more important barriers to entry include qualification (i.e. the inspection, testing, and certification of the facilities used for production, and the materials produced, to insure they meet required specifications for intended purposes) of the facility and product; financing; intellectual property rights; technical knowledge; limited defense orders; and, lack of skilled labor.

U.S. reliance on imports creates a new set of issues. Significant concentration of supply in one or just a few countries for materials with high import reliance raises diplomatic and political concerns. NDS Program analysts assess the likelihood of export controls and other actions that may restrict future access to those markets. From a risk mitigation perspective, NDS Program analysts consider the U.S.'s ability to obtain an increased share of global production in the event of a conflict scenario.

Substitution is an important area of study. NDS Program analysts examine whether potential substitutes create performance and cost issues. In addition, NDS Program analysts identify whether the substitutes are currently qualified into DoD applications and evaluate any barriers to qualification. Further, NDS Program analysts assess whether a switch to a substitute would cause dislocations further down the supply chain.

Assessing material supply chains is a complex and unique undertaking. For example, long production lead times can result in supply shortfalls even in the presence of ample capacity. In these cases, NDS Program analysts check for sufficient inventory levels at manufacturers and distributors. Sometimes, new commercial uses for an application can create unforeseen shortages and the NDS Program tries to anticipate such developments. Often, stringent military specifications render much of the world's supply of a particular material unusable for defense purposes. Supplier country reliability is yet another consideration. In some cases, a reliable supplier's facilities may be located in a non-friendly country.

Potential Shortfalls and Recommendations

To produce shortfall estimates, The Defense Logistics Agency Strategic Materials evaluates demand projections and supply considerations under an approved conflict scenario. Shortfall estimates inform stockpiling recommendations.

Chapter 1.3 Basis for the Recommendations and Plans

Material Initial/Gross Shortfalls

There were 79 materials modeled using the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) process either in whole or in part and an additional 13 materials modeled using either a bottom-up approach or other methods. With the material list, methodology, data, and assumptions in place, the following process steps were taken to estimate gross material shortfalls:

- Forecast the demand for goods and services needed over the four-year scenario period under the Base Case national emergency conditions,
- Determine the materials needed to produce the goods and services to satisfy these demands, and
- Determine the available supply of materials, taking into account that domestic single points of failure may be unable to provide material during a future national emergency
- Compare material supply with the material requirements, and compute the shortfalls.

Gross shortfalls do not account for private sector market responses to the national emergency. The term "net shortfalls" is used for the shortfalls that remain after those responses are modeled as discussed in the following chapter.

Shortfall Results and Discussion

As explained in the Executive Summary and, in keeping with the Stock Piling Act as amended, this report considers single points of failure in addition to reliance upon foreign suppliers. This report considered domestic single points of failure for beryllium, fluorspar, magnesium, and rare earth elements. Under this construct, 30 materials exhibit a gross shortfall totaling $3.183 billion. Of these 30 materials, the top-down modeling method identified gross shortfalls for 26 materials while the bottom-up method or other approaches found gross shortfalls for four materials.

Table 1.3.1 lists gross shortfalls for non-proprietary materials shown both in units and in monetary terms, evaluated with prices as of spring 2014.[2] The demand, supply, and price information for certain materials is proprietary. Accordingly, the shortfall amount and/or dollar values for these materials are withheld. Appendix 2h, which is proprietary, provides these shortfall amounts, along with other information about those materials.

[2] The material supply-demand comparison is done in terms of quantities of materials; prices are used to provide a common unit of measure for presenting the shortfall results.

Table 1.3.1: Estimated Gross Shortfall Quantities
(all dollar figures are rounded)

Number	Material	Gross Shortfall	Unit	Gross Shortfall ($, million)
1	Aluminum oxide, fused crude	281,441	short tons	$143.00
2	Antimony	26,187	short tons	$222.00
3	Beryllium metal	W	short tons	W
4	Borosilicate floated glass (one type)	7,575	metric tons	W
5	Boron carbide	W	metric tons	W
6 – 12	Carbon fiber (seven types)	W	metric tons	W
13	Chlorosulfonated polyethylene	1,271	metric tons	$11.00
14	Dysprosium	7	metric tons oxide	$3.30
15	Europium	65	metric tons oxide	$60.00
16	Fluorspar, acid grade	117,779	short tons	$32.60
17	Germanium	29,176	kilograms	$37.00
18	Graphite	82,612	metric tons	$120.00
19	Lanthanum	4,381	metric tons oxide	$50.00
20	Magnesium	105,097	metric tons	$469.00

Table 1.3.1: Estimated Gross Shortfall Quantities(continued)
(all dollar figures are rounded)

Number	Material	Gross Shortfall	Unit	Gross Shortfall ($, million)
21	Manganese metal, electrolytic	9,490	short tons	$24.60
22	Rubber (natural)	555,653	long tons	$1,136.00
23	Silicon carbide fiber, multifilament	W	short tons	W
24	Silicon carbide	28,495	short tons	$21.00
25	Tantalum	33,990	pounds Ta	$6.25
26	Tin	8,911	metric tons	$209.00
27	Tungsten	26,581,064	pounds W	$359.00
28	Tungsten-rhenium alloy	W	kilograms	W
29	Yttrium	26	metric tons oxide	$0.42
30	Yttrium oxide	W	metric tons	W
Total				**$3,183**

The majority of the gross shortfalls represent unsatisfied civilian demand totaling $2.91billion. The defense gross shortfalls, totaling $273 million result because the materials in question have single-source foreign producers or domestic single points of failure, the supply from which is explicitly prohibited from being used to satisfy defense demand (see Appendix 2d).[3] Materials that exhibit defense shortfalls include beryllium, borosilicate glass, boron carbide, carbon fiber (seven types), chlorosulfonated polyethylene, silicon carbide fiber – multifilament, tungsten-rhenium wire and, yttrium oxide (high purity). There is one shortfall material in the emergency

[3]Supplies from countries that dominate the market are not allowed to offset defense or emergency investment demand. This restriction is imposed to guard against the risk that is intrinsically associated with a concentrated supply source.

investment category.

Almost all of the civilian shortfalls occur in the first year of the scenario. One material, fused crude aluminum oxide, also has a civilian shortfall in the second year. The defense shortfalls tend to be ongoing throughout the scenario. Chlorosulfonated polyethylene (CSM) is a special case in that it has a first year civilian shortfall and an ongoing defense shortfall.

Overview of Market Response and Net Shortfalls

As the national emergency scenario commences, the private sector may engage in a number of different ways to reduce these shortfalls, resulting in net shortfalls that are considerably lower than the gross shortfalls. Both demand- and supply-side market responses may ameliorate or even eliminate gross shortfalls in the event of the national emergency postulated in the Base Case. This chapter describes the market response rationale and expands on the concept of net shortfall.

Market Response Rationale

Faced with shortfalls and rising prices for raw materials under national emergency (Base Case) conditions, U.S. manufacturers are likely to reduce demand for scarce materials as well as procure additional material supplies from available sources. At the same time, raw materials suppliers are likely to respond to higher prices by ramping up production. This behavior can be characterized as private sector "market responses."[4]

The Department of Defense (DoD) evaluated a range of potential market responses to offset or reduce the estimated Base Case gross shortfalls. The selected market response approach involved three elements: conservation/thriftiness, substitution, and an "extra sell" to the U.S. by selected foreign producers. These selected market responses are used to calculate net shortfalls which form the basis of the NDS Program's stockpiling recommendations.

Following standard economic theory, DoD postulated that material end-users would attempt to reduce the use of scarce materials in an environment of rising prices by engaging in conservation/thriftiness measures and substitution. Material end-users would also try to find additional sources of supplies for these scarce materials, albeit at premium prices, to meet their essential material demands for production. These initiatives are likely to occur even if there are no specific government actions taken to promote these efforts.

Net Shortfall Results

DoD's selected market responses produce a set of net shortfalls for each material that exhibited a gross shortfall. When the three types of market responses are aggregated they generate quite

[4] In the context of the Risk Assessment and Mitigation Framework – Strategic Materials (RAMF-SM) process and steps, the market response feature is considered step "2D."

significant reductions in gross shortfalls for several materials. Table 1.3.2 summarizes these results. Of the 30 materials exhibiting a gross shortfall, the combined market responses eliminate the shortfall for nine non-proprietary materials and ameliorate the shortfall for nine non-proprietary materials. Shortfalls for twelve materials are proprietary and are summarized in the proprietary appendices.

Table 1.3.2: Estimated Shortfall Quantities

Number	Material	Gross Shortfall (Unit)	Net Shortfall (Unit)	Unit	Net Shortfall ($M)
1	Aluminum oxide, fused crude	281,441	18,268	short tons	$9.28
2	Antimony	26,187	13,118	short tons	$111.27
3	Beryllium metal	W	W	short tons	W
4	Borosilicate floated glass (one type)	7,575	0	metric tons	$0.00
5	Boron carbide	W	W	metric tons	W
6 – 12	Carbon fiber (seven types)	W	W	metric tons	W
13	Chlorosulfonated polyethylene	1,271	216	metric tons	$1.89
14	Dysprosium	7	0	metric tons oxide	$0.00
15	Europium	65	37	metric tons oxide	$34.42
16	Fluorspar, acid grade	117,779	0	short tons	$0.00
17	Germanium (1)	29,176	17,002	kilograms	$21.68
18	Graphite	82,612	0	metric tons	$0.00
19	Lanthanum	4,381	820	metric tons oxide	$9.43
20	Magnesium	105,097	5,422	metric tons	$24.21
21	Manganese metal, electrolytic	9,490	1,480	short tons	$3.83
22	Rubber (natural)	555,653	0	long tons	$0.00

Table 1.3.2: Estimated Shortfall Quantities (continued)

Number	Material	Gross Shortfall (Unit)	Net Shortfall (Unit)	Unit	Net Shortfall ($M)
23	Silicon carbide fiber, multifilament	W	W	short tons	W
24	Silicon carbide	28,495	0	short tons	$0.00
25	Tantalum	33,990	0	pounds Ta	$0.00
26	Tin	8,911	0	metric tons	$0.00
27	Tungsten (2)	26,581,064	4,116,169	pounds W	$55.57
28	Tungsten-rhenium alloy	W	W	kilograms	W
29	Yttrium	26	0	metric tons oxide	$0.00
30	Yttrium oxide (high purity)	W	W	metric tons	W
Total					**$389.16**

(1)The stockpiling recommendation for germanium is for 10,000 kilograms at a cost of $13.6 million in addition to the 6,346 kilograms already requested.

(2)The NDS Program holds tungsten ores & concentrates in inventory and is not recommending stockpiling this material. The NDS Program has requested tungsten-rhenium alloy (quantity withheld) for the stockpile.

Demand-Side Market Responses

Conservation or thriftiness responses may be viewed as an immediate market response to shortfalls and premium prices faced in the context of the Base Case. By practicing thrift, producers try to use less of a scarce and/or very highly priced input in their production processes. By being more careful with material use (e.g., reducing waste, improving process yields, etc.), producers may be able to produce at a relatively constant rate while reducing the amount of material consumed. To assess the near-term conservation or thriftiness potential in the U.S., DoD has estimated the reduction to the gross shortfalls that would occur if U.S. buyers are able to produce key items using the lowest observed material consumption ratios (MCRs) under the 2015 Base Case assumptions for the various gross shortfall materials.

In addition to thriftiness reductions, buyers may also undertake immediate substitution efforts as quickly as possible to further reduce usage of the shortfall materials. The potential for immediate substitution of other materials, or of functional substitutes, for the Base Case shortfall materials is significant for a number of those materials (although for some the potential for immediate substitution is very limited).

Supply-Side Market Responses

In addition to the plausible demand-side market responses to the gross Base Case shortfalls, DoD also expects buyers to try to obtain additional supplies of the shortfall materials from willing sellers, both U.S. and foreign. The Base Case gross shortfalls already include all U.S. suppliers' production as part of the supply assumed to be available. However, the Base Case gross shortfalls only include the regular market share of reliable foreign suppliers' production as initially available. It is assumed to be possible for U.S. buyers to obtain a larger-than-normal share of extra production that reliable foreign suppliers could produce (albeit at premium prices). Such "extra sells" to the U.S. have occurred during past conflicts. During such engagements, imports of certain materials exhibited sharp increases associated with the beginning and cessation of hostilities.[5]

As mentioned previously, suppliers have incentive to produce at higher-than-normal levels under the higher prices that would naturally result during shortage conditions brought about by a national emergency. These premium prices vary by material, but may range from two to more than six times peacetime prices. The increase in material prices and resulting increase in production (beyond estimated peacetime production) affords the U.S. with the opportunity to gain a share of the previously unused foreign capacity.[6]

In implementing this "extra sell" from foreign suppliers to U.S. buyers, DoD has imposed certain country-specific restrictions. Rather than assuming all countries are equally willing to sell a component of their extra production to the U.S., or imposing a country-specific reliability factor,[7] the DoD has decided to assume an "extra sell" from a select set of countries. The Base Case "extra sell" market response component includes Canada, Japan and those countries that have entered into bilateral Security of Supply Arrangements (SOSAs) or a Memorandum of Understanding (MOU) with the United States, based upon the assumption of their reliability (ability and willingness) to offer extra sells.[8]

These countries are deemed reliable enough to allow the U.S. to obtain a larger-than-normal share of extra foreign production, up to 50 percent of the remainder of the extra production. While demand-side responses appear to more significantly reduce the estimated gross shortfalls

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[5] Additional details on wartime material import spikes (e.g., tungsten) are available in Appendix 3.
[6] The algorithm used to calculate the extra sell percentage appears in Appendix 3.
[7] See Appendices 2 and 3.
[8] The United States has SOSAs in place with Australia, Finland, Italy, Netherlands, Sweden, and the United Kingdom. The United States has an MOU in place with Canada.

than the supply-side market response considered for this report, this is, in part, a reflection of the conservative characteristics of the supply-side market response selected.

Part 2: National Emergency Planning Assumptions

Chapter 2.1 The Filter Research Process

The National Defense Stockpile (NDS Program) research process conducted in accordance with Section 14a of the Strategic and Critical Materials Stock Piling Act (50 U.S.C. 98 et seq) begins with a list known as the “Watch List.” In order to prioritize materials by level of importance, the Watch List is sorted by a variety of metrics so that the NDS Program can focus on the materials of most concern. The Watch List is developed in conjunction with other material selection processes that are described in Appendix 3a.

The “filter process” can be thought of as a funnel with various stages or thresholds through which a material on the Watch List must pass before it is considered as a study candidate. It is important to note that not every material on the Watch List will make it all the way down the filter if NDS Program analysts determine that (A) the material falls outside of its purview; (B) the material risk is due to a price spike; (C) the cost/benefit analysis does not warrant action; or (D) the proposed action is beyond the authority of the NDS Program. Materials for which the U.S. has a foreign dependence or those for which a single point of failure (foreign or domestic) exists along any link/node in the supply chain receive special consideration.

The NDS Program employs a staff of experienced economists and market analysts that continuously monitor materials markets for “trading anomalies.” These anomalies can take a variety of forms and can be characterized as short-term (tactical) or long-term (strategic) disturbances. In the short-term price spikes, industrial accidents, infrastructure problems, labor action, natural disaster, terrorism, or logistics bottlenecks can cause short- and medium-term disruptions (defined as 6 months to one year) in the flow of materials. The analytical process involves determining the nature, cause, severity and consequences of these short-term disturbances. Some of the factors contributing to the severity of a supply disruption include the closure or temporary idling of a key link in the defense industrial base; a reliance on a sole or single source supplier that is financially, competitively or operationally weak; and, the partial or complete stoppage in the flow of a required material due to, for example, force majeure (Act of God or chance occurrence), or the increased reliance on a foreign supplier.

Trading anomalies can also involve long-term disruptions to supply chains and material flows. These types of disturbances typically encompass longer term “megatrends” that take years and often decades to play out. Megatrends are long-term societal shifts that change not only the type but very nature of human activity. These include things like technological change, major changes in the composition of the economy, industrialization (and de-industrialization) and, demographic shifts just to name a few.

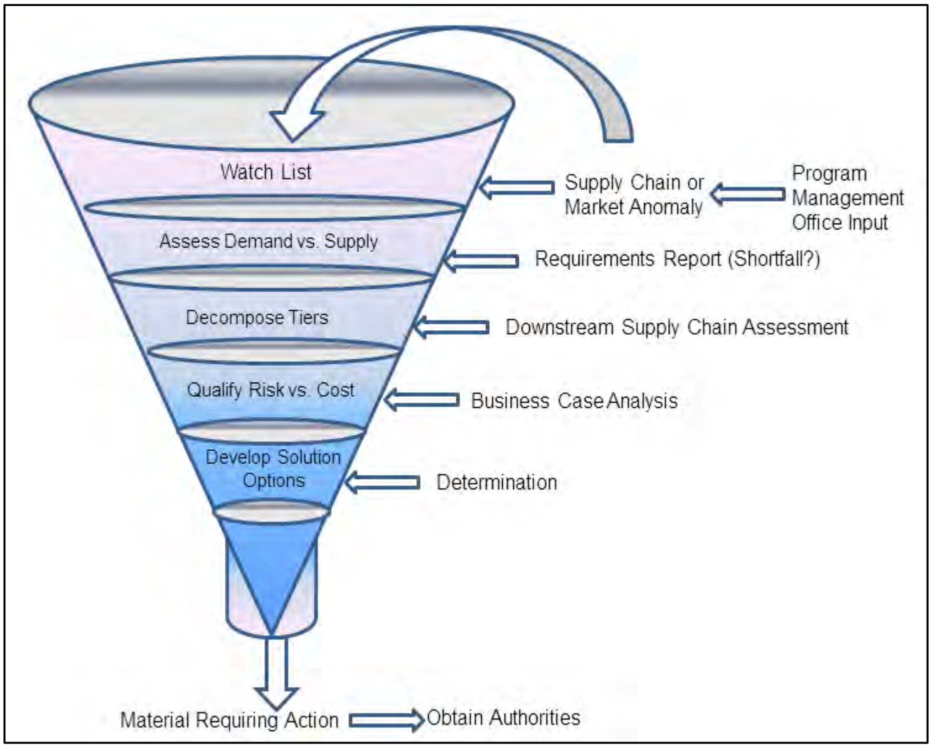

Figure 2.1.1: Research Process for Stockpiling Materials

Economic Research

As mentioned above, NDS Program economists conduct continual market surveillance and forecasts of global markets. In order to conduct their work, they maintain subscriptions to industry journals, news agencies, and trading platforms, as well as access to research from consultants, academia, government-run laboratories and other government agencies on the global market for materials. The NDS Program works with private industry and the military to ascertain and evaluate both short- and long-term material availability, industrial base capability, and supply chain vulnerabilities for strategic and critical materials.

Demand side analysis presents additional challenges due to the difficulty in estimating DoD demand for materials that are often buried deep in the supply chain several tiers below the systems integrator, original equipment manufacturer (OEM) or even Tier 1 suppliers. While many OEMs and Tier 1 suppliers expend enormous effort and resources to understand their supply chain, full knowledge of the complete materials supply chain is simply not practicable or feasible in many cases. Furthermore, the DoD is typically a small buyer of materials in both volume and value-added terms. Developments in the commercial sector are what really “drive” the demand for materials. Fortunately, there is a rich body of data available from governments, private consulting groups, associations, non-profits, and some of the lower tier companies themselves that can greatly facilitate demand-side analysis for materials.

Forecasting mineral and metal supply is also fraught with uncertainty. Estimating the amount of a resource involves complex statistical sampling techniques, geological data and an understanding of the morphology of the underlying resource. The NDS Program has access to the expertise and data provided by the United States Geological Survey (USGS). Each year, the USGS publishes the Mineral Commodities Summary – a compendium of data and information on global mine supply for many of the materials of interest to the NDS Program. The NDS Program uses USGS and other data to assemble production and capacity estimates globally and, where possible, by country/region.

Downstream Assessments

Materials with shortfalls under Base Case conditions or materials with a real-time requirement from a military service or defense agency program office will receive downstream supply chain assessments. Downstream assessments are supply chain "deep dives" that deconstruct the supply chain in further detail. A deep dive goes beyond the top line analysis of the raw material to include subsequent supply nodes, the components that are manufactured from those materials, where they are manufactured, by whom and, in some cases, which weapons systems they support. The deep dive is an intrinsically investigative process requiring data integration, search and discovery, knowledge management, and collaboration. In order to facilitate the development of deep dive assessments, the NDS Program partnered with Oak Ridge National Laboratories and technology firm Palantir Technologies to develop the Strategic Material Analysis & Reporting Topography (SMART) analytical tool. A more detailed discussion of SMART is presented in Chapter 4.

Deep dive assessments inform and support the Business Case Analysis (BCA) which identifies risk consequences and recommends mitigation solutions along with the respective costs and benefits. From the BCA, a final Determination is developed that includes recommended actions (including doing nothing) along with associated costs and benefits. The BCA and Determination form the foundation for the legislative proposal and budgetary processes.

Chapter 2.2 Overview of Base Case

Sections 14b and 14c of the Strategic and Critical Stock Piling Act require the National Defense Stockpile (NDS Program) to utilize the four-year national emergency planning assumptions referred to as the Base Case. This scenario assumes one year of conflict followed by three years of recovery/regeneration. The Base Case must include estimates of all relevant defense sector demands including those necessary to regenerate weapon systems lost and munitions expended in the conflict and essential civilian sector demands. The national emergency planning assumptions must be consistent with the scenarios used in normal Department of Defense (DoD) planning.

The 2015 NDS Program Base Case scenario draws from elements of the Integrated Security Constructs (ISCs) for which the United States (U.S.) must be prepared. ISCs are classified, priority Defense Planning Scenarios promulgated by the Secretary of Defense for DoD programming and budgeting purposes. For the purpose of this analysis, the Base Case scenario is postulated to cover four whole years, 2017-2020.

The conflict portion (which occurs within the first scenario year) was constructed as a hybrid to include the following: (1) a catastrophic attack on a U.S. city by a foreign terrorist organization or rogue state; (2) two near-simultaneous major combat operations (state vs. state conflicts); (3) war damage from a highly capable aggressor, and (4) ongoing foundational activities, (i.e., deterrence, forward presence, and building partner capacity). The combination of these four areas addresses the statutory requirements for the NDS Program Report to Congress while also conforming to the Office of the Secretary of Defense (OSD) Policy guidance.[9]

Replacement requirements for weapon losses and munitions expenditures in the major combat operations were developed by the Office of the Secretary of Defense/Cost Analysis and Program Evaluation (OSD/CAPE). The foundational activities are assumed not to generate any requirements for materials over and above those induced by DoD's Future Year Defense Program (FYDP) spending.

Subsequent-year Base Case activities include repair of homeland damage, building the replacement requirements for the weapon losses and munition expenditures, continuing the foundational activities, and also continuing with regular Fiscal Year 2017–2020 FYDP acquisitions.

Section 14b of the Stock Piling Act directs that the DoD describe the content of a number of specified national emergency planning assumptions used to estimate requirements for the NDS

[9] OSD Policy would like to highlight that these scenarios: (a) are estimates of future demands, (b) reflect the current strategy (i.e., it's not a post-sequestration strategy), and (c) are not force-managed in conjunction with other contingencies. These products are in the process of being revised and there may be potential changes to forces and Concept of Operations (CONOPS).

Program. Information on each of the planning assumptions mentioned in Section 14b is provided below.

The Base Case included 79 materials for RAMF-SM modeling (partial or full suite of models) 27 of which are proprietary or classified.

Budget and Defense Planning Scenario

Length and Intensity of the Conflict

The military conflict for which material requirements are calculated lasts for roughly one year. (See Appendix 2g, which is classified, for details, including information on the intensity of the conflict.)

Mobilized Force

The scenario assumes that the warning time is too short to build new forces and that the United States has sufficient existing forces to meet the requirements for defeating the enemy.

Anticipated Losses

As stated earlier, the anticipated platform losses and munitions expenditures are developed by OSD/CAPE. The information is classified, and appears in Appendix 2g.

Military Requirements

Military sector demand is estimated to be $4.05 billion (2014 dollars). The 2015 Base Case military sector demand represents approximately 3.1 percent of the overall four-year Base Case scenario demand ($130.2 billion) for the 68 non-proprietary materials included in the Base Case.[10] Base Case demand includes 68 non-proprietary materials and is the dollar value required over the four-year Base Case scenario for the manufacture of goods and services for the military, emergency investment, and essential civilian sectors.

Industry Requirements

Industrial, emergency investment is estimated to be $116 million (2014 dollars.) This represents less than one tenth of one percent of the overall four-year Base Case scenario demand ($130.2 billion) for the 68 non-proprietary Base Case materials. The industrial or emergency investment, sector is limited to materials needed to meet requirements for new plant and equipment to overcome any capacity shortfalls caused by accelerated production of defense goods during the four-year emergency scenario period.

[10] See Appendix 2b for a description of the methodology used in calculating these demands.

Essential Civilian Requirements

Essential civilian demand is estimated to be $126.1 billion (2014 dollars.) Demand by this sector represents approximately 96.8 percent of the overall Base Case scenario demand ($130.2 billion) for the 68 non-proprietary Base Case materials. The essential civilian sector includes the dollar value of those materials that are needed over the four-year scenario period in the economy for the manufacture of essential goods and services for the civilian sector.

Foreign Supplies

The available supplies of materials from foreign sources are defined as those expected to be available to the United States during the military conflict year and the subsequent regeneration period after accounting for supplier country reliability, anti-U.S. sentiment, the U.S. market-share, supplier country war damage, shipping losses, and "market dominator" criteria. (See Appendices 2b and 2d for a discussion of these factors.) The list of such supplies available during the roughly one year of mobilization and military conflict and each year of regeneration, for the materials analyzed, is considered classified and proprietary, and appears in Appendix 2g.

Domestic Production

Total domestic production levels are estimated for the materials considered during the roughly one year of military conflict and three years of regeneration. Some of the estimates are considered proprietary information. For this reason, the table of domestic production levels appears in Appendix 2h.

Civilian Austerity Measures

The Base Case scenario assumes that the federal government will not necessarily take any regulatory measures to curtail or prevent the production of nonessential civilian goods and services. Nevertheless, there are decrements imposed on normal projected civilian sector demands for the period to eliminate nonessential civilian goods and services, in accordance with the requirements of the Stock Piling Act.[11] These decrements are based on the advice of a working group made up of representatives from several non-Defense government agencies. See Appendix 2e for further details.

[11] The normal projected civilian sector demands are consistent with the Council of Economic Advisors' 2013 Mid-Session Review and the FY 2015 President's Budget.

Part 3: Recommendations under Alternative Mobilization Periods and Military Conflict Scenarios

Chapter 3.1 Recommendations under Alternate Cases

As mandated in the Strategic and Critical Materials Stock Piling Act, the Department of Defense (DoD) analysis of material stockpiling requirements relies on a Base Case specifically linked to current national planning scenarios. The law also mandates that DoD conduct analysis of alternative cases that incorporate more stressful assumptions about the nature and duration of the national emergency, international environment, and U.S. response. Part 3 of this report examines several different alternative cases.

It should be noted that each Alternate Case and the Closed Economy scenario discussed in Part 3 of this report was modeled through RAMF-SM. As such, only 68 of the 79 materials that were modeled either fully or partially in RAMF-SM could be treated in the Alternate Cases and the Closed Economy Scenario.

Chapters 3.2 and 3.3 analyze a variety of cases that involve a number of more stressful assumptions, including:

- Occurrence of additional homeland defense events;
- More severe and/or longer-lasting disruptions to foreign trade and material imports;
- Increased post-conflict Future Years Defense Program (FYDP) spending;

The Alternate Cases do not consider the effect of the conflict scenario on domestic single points of failure. Therefore, the Alternate Cases are compared to the Base Case results excluding the shortfalls that result from including domestic single points of failure.

The term “Alternate Cases” is used to refer specifically to those cases described in Chapters 3.2 and 3.3.

Chapter 3.4 examines a different kind of case that involves restrictions on imports; specifically, a “closed economy” case in which both foreign supply of materials and imports of goods and services are cut off for one year, with goods and services exports also being set to zero.

Summary of Alternate Cases Analysis

Analysis of potential shortfalls across this range of possibilities revealed several key points.

The most stressful Alternate Case generated a total gross shortfall (including supply from single points of failure) of $3.69 billion.

Across all Alternate Cases, civilian shortfalls comprise the vast majority (over 97 percent) of total shortfalls. Increased combat scenarios and post-conflict defense spending slightly increase defense shortfalls, but defense never accounts for more than 2.5 percent of total shortfall by value.

The composition of material shortfalls remains relatively constant across each of the Alternate Cases. More stressful Alternate Cases increase the *size* of shortfalls, but generally do not create *new* shortfalls.

Disruptions to foreign trade – both goods and services, and the supply of material imports – account for most of the civilian, and hence total, shortfalls. They do not significantly affect defense shortfalls.

The occurrence of an extra homeland event does not significantly affect either civilian or defense shortfalls. This counter-intuitive result is explained by specific assumptions about the homeland event, as detailed in the classified Appendix 4.

Increased FYDP spending increases defense specific material shortfalls. FYDP spending causes the majority of the defense material shortfall increases, indicating that defense material shortfalls are directly related to DoD spending levels.

Chapter 3.2 Description of Alternate Cases

This chapter describes the Alternate Cases evaluated. These Alternate Cases are based upon the Base Case planning scenario but include modifications that affect both material demand and supply. These modifications result in increased material shortfalls, and hence, the potential development of different mitigation strategies stemming from these shortfalls. The individual modifications are termed scenarios, and for the purpose of the unclassified description, are referred to generically as scenario 1, 2, or 3.

Below is a description of the conditions and assumptions for the various Alternate Cases. Specific detail on the Alternate Cases and combat scenarios is available in classified Appendix 4.

Alternate Case I

Alternate Case I (AC-I) represents a plausible "worst-case scenario." As in the Base Case, AC-I models one year of conflict followed by three years of regeneration. The U.S. suffers two homeland attacks (as opposed to one in the Base Case). The U.S. enters combat in scenario 1 and scenario 3, as per the Base Case. Political tension persists even after the end of conflict. Adversaries supplies are withheld for an additional year as a coercive tactic, and the scenario 2 country also imposes a trade disruption against the U.S.

Believing that these antagonistic relations will continue, the U.S. launches a major defense build-up above and beyond regeneration of the base military force. Future Years Defense Program (FYDP) funding is increased by 50% in order to enhance conventional deterrence against adversaries and reassure allies of U.S. resolve. Table 1 presents a summary of the AC-I scenario assumptions.

Table 3.2.1: AC-I Scenario Assumptions Compared to the Base Case

	Scenarios 1 and 3	Scenario 2	Homeland Event	FYDP	Build-Up	Supply Restriction
Base Case	Expenditure and attrition	Country reliability	One event	100 percent	None	One year
AC-I	Expenditure and attrition	Country reliability	Two events	150 percent	None	2 years

Alternate Case II

As in AC-I, Alternate Case II (AC-II) models conflict against the scenario 1 and 3 adversaries, longer supply disruptions, and a 50% FYDP increase. However, AC-II only models one homeland event. Because the number of homeland events is the only difference between AC-I and AC-II, the sensitivity of material shortfalls to the occurrence of additional homeland events can be assessed. If AC-II results in much smaller shortfalls than AC-I, material shortfalls are highly sensitive to the occurrence of additional homeland events; if shortfalls do not significantly decrease, they are relatively insensitive.

Table 3.2.2: AC-II Scenario Assumptions Compared to the Base Case

	Scenarios 1 and 3	Scenario 2	Homeland Event	FYDP	Build-Up	Supply Restriction
Base Case	Expenditure and attrition	Country reliability	One event	100 percent	None	One year
AC-II	Expenditure and attrition	Country reliability	One event	150 percent	None	2 years

Alternate Case III

Alternate Case III (AC-III) explores the implications of defense spending higher than the Base Case but lower than in AC-I and AC-II. AC-III models conflict against the scenario 1 and 3 adversaries, longer supply disruptions, and two homeland events. FYDP spending is postulated to increase by 25%, compared to 50% in AC-I and AC-II.

Table 3.2.3: AC-III Scenario Assumptions Compared to the Base Case

	Scenarios 1 and 3	Scenario 2	Homeland Event	FYDP	Build-Up	Supply Restriction
Base Case	Expenditure and attrition	Country reliability	One event	100 percent	None	One year
AC-III	Expenditure and attrition	Country reliability	Two events	125 percent	None	2 years

Alternate Case IV

Alternate Case IV (AC-IV) is the least-stressing Alternate Case. AC-II models a two-year supply disruption and 25% FYDP increase.

Table 3.2.4: AC-IV Scenario Assumptions Compared to the Base Case

	Scenarios 1 and 3	Scenario 2	Homeland Event	FYDP	Build-Up	Supply Restriction
Base Case	Expenditure and attrition	Country reliability	One event	100 percent	None	One year
AC-IV	Expenditure and attrition	Country reliability	One event	125 percent	None	2 years

Chapter 3.3 Results of Alternate Cases

This chapter reports the changes in material shortfalls that arise from the Alternate Cases. These results are reported at an aggregate level. Material-by-material analysis is available in the classified Appendix 4. Results from each Alternate Case are presented individually first, and then compared to each other.

It should be noted that the Alternate Cases do not consider the effect of the conflict scenario on domestic single points of failure.

Alternate Case I

AC-I's stressing conditions significantly increase the dollar value of the shortfall (in 2014 dollars).

- *Total* gross shortfalls of 24 materials valued at $3.69 billion.
- *Civilian* gross shortfalls remain at 15 materials but rise to $3.61B.
- *Emergency Investment* gross shortfall of 1 material and $1.56M.[12]
- *Defense* gross shortfalls increase to 10 materials and $85.18M.

Further analysis of these results indicates that the civilian and defense sectors exhibit varying degrees of sensitivity to scenario changes. An additional year of supply disruption dramatically increases civilian and total shortfalls but minimally affects defense shortfalls. The extra homeland event affects civilian shortfall more than defense or emergency investment but accounts for less than one percent of each sector's shortfall. Table 3.3.1 shows AC-I scenario conditions added one at a time in order to illustrate the varying sensitivity of defense and civilian-dominated total shortfalls.

Table 3.3.1: Individual Examination of AC-I Scenario Conditions

Scenario Conditions	Total Shortfall ($ Million)	Delta	Defense Shortfall ($ Million)	Delta

[12] The industrial sector covers the construction of new plants and/or the manufacture of new equipment in the private sphere to overcome bottlenecks caused by accelerated production during a national security emergency. These bottlenecks are estimated by comparing defense-related and essential civilian requirements to the emergency operating capacity of existing plant and equipment. (In practice, this sector may be thought of most appropriately as the "emergency investment" sector.)

Scenario Conditions	Total Shortfall ($ Million)	Delta	Defense Shortfall ($ Million)	Delta
BASE CASE	$2,637.52	–	$41.27	–
2 year supply restriction	$3,465.58	$828.06	$41.30	$0.03
50 percent FYDP increase	$3,657.30	$191.72	$84.72	$43.42
extra Homeland event	$3,693.73	$36.43	$85.18	$0.47
AC-I FULL SCENARIO	$3,693.73	$1,056.21	$85.18	$43.92

The total shortfall is driven by the civilian sector and is most strongly affected by the two-year supply disruption. Defense shortfalls are most affected by the 50 percent FYDP increase.

Alternate Case II

AC-II with one homeland event results in the following gross shortfalls:

Total: 24 materials, $3.66B

Civilian: 15 materials, $3.57B

Emergency Investment: 1 material, $1.56M

Defense: 10 materials, $84.72M

These findings indicate that strategic material shortfalls are relatively insensitive to the occurrence of an additional homeland event. As with AC-I, the civilian shortfall increases relative to the Base Case is relatively large and driven by the two-year foreign supply restriction, while defense shortfalls are relatively small and driven by the FYDP increase.

Alternate Case III

AC-III results in gross shortfalls larger than those estimated in the Base Case but smaller than those estimated for either AC-I or AC-II:

Total: 24 materials, $3.59B

Civilian: 15 materials, $3.53B

Emergency Investment: 1 material, $1.58M

Defense: 10 materials, $58.07M

Alternate Case IV

AC-IV gross shortfalls are larger than the Base Case, but smaller than AC-I, AC-II, and AC-III:

Total: 24 materials, $3.56B

Civilian: 15 materials, $3.50B

Emergency Investment: 1 material, $1.57M

Defense: 10 materials, $57.61M

Comparison of Alternate Cases and Summary of Findings

Comparing the results of the various Alternate Cases reveals several insights. Most obviously, more stressful cases than the Base Case increase shortfall amounts. Across all cases, the assumption of a two-year supply disruption accounts for the largest total material shortfall increase. The shortfall caused by the supply disruption is concentrated in the civilian sector and does not significantly affect the defense sector. Defense shortfalls are most sensitive to FYDP increases. Shortfalls, whether in the civilian or defense sectors, are relatively insensitive to the occurrence of an additional homeland event.

Chapter 3.4 Closed Economy

For many strategic and critical materials, the United States is reliant, at least to some extent, upon foreign sources of supply. In addition, the United States imports many goods and services. Since imported goods do not have to be manufactured domestically, they can satisfy final demand without creating a strain on U.S. industrial production capabilities.

The Base Case assumes that both foreign material supplies and imports of goods and services are decremented to some extent from their peacetime levels to account for supplier country war damage, shipping losses, reduced ability to produce, and unwillingness to sell to the U.S. in the context of the national emergency planning scenario. U.S. exports of goods and services are also decremented to some extent for two reasons. First, the U.S. might need some of the goods it otherwise would export. Second, goods manufactured for export constitute a source of material demand on U.S. industry, a demand which might lead to excessive use of already-scarce materials.

It is natural, then, to consider an extreme case such as this in order to estimate an upper limit for material shortfalls. In such a scenario imports of materials, imports of goods and services, and/or exports of goods and services are set to zero in the model. This is reminiscent of what economics textbooks refer to as a "closed economy" in which a country is totally self-sufficient.

Of course, if the United States had truly been a closed economy, with no exports and imports for an extended period of time, its demand and industrial production patterns would be far different than they are currently. But for the purposes of this chapter, the term closed economy simply means a complete cutoff of U.S. imports and/or exports of materials and/or goods/services.

Closed Economy Case

The main closed economy case of interest posits the following conditions:

- No foreign supplies (i.e., imports) of material for the first year of the scenario
- No (U.S.) imports of goods and services for the first year of the scenario
- No exports of goods and services for the first year of the scenario.

The civilian and military demands for goods and services remain as in the Base Case. If imports for final goods and services are cut off they must be met by increased domestic production which, in turn, increases the demand for materials. However, the reduction in exports serves to decrease the demand on U.S. industrial production which, in turn, reduces the industrial sector's demand for materials.

A cautionary note concerning emergency investment demand is in order. In general, the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) models regard reduction of imports as causing an increased demand for output of U.S. industry. If projected steady-state industrial output, expanded at least partially toward full capacity, is insufficient to meet this increased demand for output, some amount of emergency investment to build new productive capacity is considered necessary. RAMF-SM calculates the additional demand on industry to build that new capacity. Unfortunately, if imports are reduced to zero, technical problems with RAMF-SM prevents those equations from running. So for the closed economy case, the Base Case emergency investment demand was used.

Given the above assumptions and caveats, the shortfall results for the closed economy case are shown in Table 3.4.1 below. The total shortfall amount is $29,142 million, about a nine-fold increase over the Base Case shortfall value (including single point of failure) of $3,180 million.

Table 3.4.1: Material Gross Shortfalls under Closed Economy Case

		Shortfall Amount	
Material	**Units**	**in Units**	**in $M [a]**
Aluminum lithium alloys	metric tons	0	$0.00
Aluminum oxide, fused crude	short tons	430,496	$218.70
Antimony	short tons	30,469	$258.44
Beryl ore	short tons	0	$0.00
Beryllium copper master alloy	short tons	1,360	$21.57
Beryllium metal	short tons	W	W
Bismuth	pounds	2,946,763	$31.38
Boron	MT Oxide	1,676,389	$2,828.91
Carbon fiber (13 types)	metric tons	W	W
Cerium	MT Oxide	0	$0.00
Chromium, ferro (Ferrochromium)	short tons	904,752	$1,556.35
Chromium metal	short tons	5,240	$44.01
Cobalt	pounds Co	16,005,255	$216.07
Chlorosulfonated polyethylene (CSM)	metric tons	4,135	$36.18
Dysprosium	MT Oxide	43	$19.90
Erbium	MT Oxide	7	$0.72
Europium	MT Oxide	99	$91.34
Fluorspar, acid grade	short tons	706,943	$195.60
Fluorspar, metallurgical grade	short tons	28,187	$6.39
Gadolinium	MT Oxide	0	$0.00
Gallium	kilograms	40,484	$11.13
Germanium	kilograms	56,869	$72.51
Graphite	metric tons	223,420	$324.63
Indium	metric tons	79	$60.31
Iridium	troy oz.	72,318	$72.27
Lanthanum	MT Oxide	1,213	$13.95
Lead	short tons Pb	916,604	$2,114.71

Table 3.4.1: Material Gross Shortfalls under Closed Economy Case (continued)

Material	Units	Shortfall Amount in Units	Shortfall Amount in $M [a]
Lithium	metric tons	0	$0.00
Magnesium	metric tons	165,790	$740.15
Manganese, ferro (Ferromanganese)	short tons	397,018	$359.64
Manganese metal, electrolytic	short tons	28,092	$72.76
Manganese ore chemical/metal grade	short dry tons	731,027	$3.26
Minor rare earths (Ho Tm Yb Lu)	MT Oxide	0	$0.00
Neodymium	MT Oxide	0	$0.00
Nickel	short tons Ni	350,838	$5,875.36
Niobium (Columbium)	pounds Nb	24,313,307	$463.19
Palladium	troy oz.	3,814,183	$3,091.40
Platinum	troy oz.	1,082,789	$1,567.88
Polypropylene fiber	pounds	0	$0.00
Praseodymium	MT Oxide	0	$0.00
Quartz crystals (synthetic)	metric tons	0	$0.00
Rhenium	pounds	90,171	$110.46
Rubber (natural)	long tons	2,654,186	$5,425.66
Samarium	MT Oxide	0	$0.00
S-glass (one type)	metric tons	0	$0.00
Silicon carbide	short tons	218,060	$161.15
Strontium	metric tons Sr	27,573	$38.10
Tantalum	pounds Ta	1,554,889	$285.64
Tellurium	metric tons	52	$5.60
Terbium	MT Oxide	0	$0.00
Tin	metric tons	50,832	$1,190.82
Tungsten	pounds W	40,549,325	$547.42
Vanadium	short tons V	0	$0.00
Yttrium	MT Oxide	205	$3.27
Yttrium oxide	MT	W	W
Zinc	short tons	514,436	$926.68
		Total shortfall value	$29,142.00

[a] Evaluated with prices current as of Spring 2014; total is rounded
W = withheld to avoid disclosing proprietary information

Part 4: Plans of the Stockpile Manager

Chapter 4.1 Materials Authorized for Acquisition

Section 14(e) of the Stock Piling Act states that the President "shall submit with each report under this Section a statement of the plans of the President for meeting the recommendations of the Secretary set forth in the report."

Section 16(a) of the Stock Piling Act states that the President "shall designate a single Federal office to have responsibility for performing the functions of the President under this Act, other than under Sections 7(a)(1) and 13." Section 16(b) of the Stock Piling Act designates this officer as the "National Defense Stockpile Manager."

The FY 2014 National Defense Authorization Act (NDAA) granted the stockpile manager the authority to acquire six materials for the National Defense Stockpile (NDS Program):

(1) cadmium zinc tellurium (CZT);

(2) ferroniobium;

(3) dysprosium metal;

(4) yttrium oxide;

(5) lithium-ion precursors;

(6) triaminotrinitrobenzene (TATB) and insensitive High Explosive (IHE) molding powders

These six materials are necessary to meet the U.S.'s military, industrial, and essential civilian needs during a national emergency.

The shortfall for dysprosium metal and yttrium was based on the analysis from the FY 2013 Requirements Report. The legislative authority for ferroniobium is based on the observation that Brazil is the dominant supplier for this material. Relying on a single supplier during a national emergency constitutes a risky or dangerous reliance. Program managers for the affected weapons systems identified the shortfalls in CZT, lithium-ion cell precursors, TATB and IHE molding powders.

Chapter 4.2 Reclamation Plans

The NDS Program has started to transfer excess strategic materials from other government agencies into the Stockpile under the authority of Section 4 of the Stock Piling Act. The transfer of excess materials is a cost effective method to reconstitute the NDS Program inventory. As of 2014, the NDS Program Manager has transferred government-owned quantities of tantalum, iridium, beryllium, titanium, and nickel-based super alloys into the NDS Program.

Authorities granted in the FY 2014 NDAA allow the NDS Program to recover strategic materials from excess government assets. This means the NDS Program can start recycling excess government materiel in order to create an alternative domestic supply of strategic material feedstock.

The NDS Program plans to execute this process on a trial basis using excess aerospace turbine engine components from Tinker Air Force Base in Oklahoma City, OK. Preliminary work by the Air Force proves that proper reclamation techniques can recover strategic materials including vacuum induction melt (VIM) nickel-based super alloys containing tantalum, niobium, tungsten, and rhenium. The recovered materials can meet specifications that allow their re-use as aerospace grade material.

Chapter 4.3 The Study of Future Material and Mobilization Requirements for the Stockpile

The study of future material and mobilization requirements for the NDS Program is permitted under Section 9(b) (2) (E) of the Stock Piling Act. The risks facing the United States stemming from dependence upon foreign sources and single points of failure for materials require continuous monitoring of the global marketplace.

Under this effort, the NDS Program Manager has a number of ongoing projects that identify and quantify material requirements in a constantly changing global supply chain. Continued support for these efforts ensures that the NDS Program develops and maintains the most current tools for evaluating the supply chains for current and future material requirements and mobilization scenarios for the NDS Program.

As summarized in the Executive Summary and explained in Chapter 2.1, the NDS Program maintains a “Watch List” of materials that are of interest to the Department, military services and defense agencies. From this list, a subset undergoes further research and modeling. The following subsections describe ongoing efforts in these areas. The first subsection lists the materials recommended for further study while the second describes a collaboration and data analysis tool that analysts at the NDS Program now use for downstream supply chain evaluations.

Materials Requiring Further Study

In addition to regular monitoring of all materials on the Watch List, certain materials require more study. Significant reliance upon foreign sources and/or a single point of failure is the main basis for recommending further study. In general, the NDS Program pursues further study if a material is in net shortfall, if it has a significantly large gross shortfall or, if direct observation uncovers a supply chain issue in the programs that use those materials.

Materials that are in net shortfall undergo further study in order to build a business case for the acquisition and also to determine, and where possible quantify, its use in the defense industrial base. Finally, further study identifies the optimal form(s) of a material to stockpile.

Materials with a potential for supply chain disruption also undergo further study. Identifying the node in the supply chain that is most likely to fail is the focus of these studies. This research requires collaboration with the agencies and programs experiencing disruptions.

Ultimately, these studies should inform a decision on the optimal quantity and form of material to stockpile. It is also possible that additional research will demonstrate that stockpiling is sub-optimal and that other governmental authorities such as the Defense Priorities and Allocations System (DPAS), Title III or ManTech would be more effective.

Table 4.4.1 lists these materials and describes the key concerns warranting additional study.

Table 4.4.1: Materials Recommended for Further Study

Material	Background
Carbon fiber, pitch-based	Pitch-based carbon fibers are critical to aerospace and weapons platforms where thermal conductivity and strength are necessary properties. There are currently no substitute materials with equivalent thermal conductivity. There is a single confirmed domestic producer, and only two other foreign producers. Only one of those foreign producers is currently supplying for defense applications.
Gallium	Gallium is an essential element for compound semiconductors used in many ground and space microwave transistor and integrated circuit applications. Gallium provides the high efficiency, high frequency, high power, and low noise properties critical for satellite communications. Microwave power transistors using gallium nitride (GaN) are becoming increasingly important because of the substantial reductions in weight in future satellites. Solar cells for spacecraft power generation also use GaN. Furthermore, the U.S. relies on imports for all of its 33.5 tons of annual primary gallium consumption. A report published by the European Union (EU) in May 2014 also highlighted gallium's importance. The report listed gallium as critical in terms of economic importance and supply risk. The EU report forecasts gallium demand to grow by 8 percent per annum through the year 2020. Despite rapidly growing demand, the EU report, citing projections from consulting firm Roskill, forecasts a small deficit for gallium in 2015. This is expected to which will turn into a large surplus by 2020. On the supply-side, production of gallium is price-sensitive and potentially more gallium (which is a by-product of alumina refining) could come from alumina refineries with appropriate investments should the price of gallium rise. There is no shortage of gallium within the waste streams of these alumina refineries and global reserves of bauxite (the ore used to manufacture alumina) are plentiful.
Graphite, natural flake (top quality)	One key sub-segment of the market for graphite is in high demand whilst supply adequacy is uncertain. Li-Ion batteries use top quality flake graphite. Expandable graphite, a developing technology with applications as flame-retardants, also uses top quality flake graphite. Demand for top quality natural flake graphite has led to recent exploration activity mainly in Canada but exploration often fails to result in production.

Table 4.4.1: Materials Recommended for Further Study (continued)

Material	Background
Hydroxyl-terminated polybutadiene (HTPB)	Please see proprietary section.
Indium	Indium is a primary constituent in the indium tin oxide (ITO) used in transparent electrodes for photovoltaic solar cells and touch screens. Indium is also an important component of semiconductors used in microwave transistors and light emitting diodes (LEDs). Indium is primarily a byproduct of zinc mining. Specific applications for space include semiconductors for monolithic microwave integrated circuits (MMICs), optoelectronics and focal plane arrays. Annual U.S. consumption of indium is approximately 114 metric tons all of which comes from imports, mainly from China, Canada and Japan. China, which accounts for 75 percent of world reserves and 50 percent of world production, has implemented export quotas on indium. The NDS Program did not find a net shortfall of indium in the 2015 Base Case National Emergency Planning Assumptions. However, the concerns raised by the NSS deserve further study. The NDS Program would recommend stockpiling in the event that research uncovered a potential net shortfall for indium.

Table 4.4.1: Materials Recommended for Further Study (continued)

Material	Background
Natural Rubber	Given the large projected shortfall of natural rubber in the FY 2015 Requirements Report (~556,000 long tons @ $1.2 billion) that falls to zero following anticipated market responses (thriftiness, substitution and spot buys) NDS Program economists suggest soliciting the views of industry, DoD agencies and MLSVCS regarding rubber availability and projected demand. According to the International Rubber Study Group (IRSG), global production of rubber totaled 27.5 million metric tons in 2013 of which 43.7 percent, or 12.04 metric tons was natural rubber with the balance synthetic rubber. In the natural rubber segment, Asia continues to dominate world production accounting for 11.2 million metric tons, or 93 percent of the total in 2013. Thailand and Indonesia remained the top two suppliers of natural rubber in 2012 (the latest data available) with production totaling 3.5 million and 3.04 million metric tons, respectively. Global production of synthetic rubber totaled 15.5 million metric tons in 2013 of which 4.7 million metric tons consisted of styrene butadiene rubber (SBR). Since synthetic rubber is a derivative of petroleum production, the production of synthetic rubber is less concentrated than the production of natural rubber. Judging from the export statistics for SBR, Germany, the United States, Belgium, the Netherlands and South Korea are top producers of this type of synthetic rubber. Current market conditions indicate a supply glut, falling prices and rising inventories for natural rubber. According to an August 18, 2014 report in Bloomberg, that cites data from The Rubber Economist Ltd., global inventories of natural rubber will rise from 2.9 million metric tons in 2013 to 3.79 million metric tons by the end of 2014 as production continues to rise in an environment of soft demand. However, rubber farmers are likely to reduce production in response to low prices. This should shrink the production surplus heading into 2015 and 2016. Future research into the markets, demand for and supply of natural and synthetic rubber will determine if the markets could support the substitution of over a half million long tons of natural rubber to synthetic rubber.
Scandium	Downstream research identifies a potential shortfall. The U.S. has limited domestic capability for downstream forms of scandium and is 100 percent import reliant for scandium oxide.

Table 4.4.1: Materials Recommended for Further Study (continued)

Material	Background
Tourmaline	Tourmaline is notable for its piezoelectric properties (produces an electrical response to a mechanical load) and functionality at high temperatures. High temperature, piezoelectric accelerometers and sensors require flawless or near-flawless natural tourmaline. Sensor manufacturers have publically announced supply issues of accelerometers due to supply chain issues with tourmaline. Further study needed to consider stockpiling of tourmaline to support defense requirements.
Vacuum Induction Melt (VIM) turbine engine alloys	The NDS Program recommends the investigation of the primary and secondary metal requirements for domestic manufacturing of turbine engine components such as blades and vanes. Alloy requirements of interest include nickel, cobalt, and titanium super alloys including alloys that contain elements such as tungsten, tantalum, niobium, and rhenium. One goal of the assessment is to determine whether the defense industrial base can meet defense requirements for production of VIM aerospace alloys during a material supply disruption. A second goal of the assessment is quantitative modeling of the impact on supply if the Government were to reclaim VIM alloys from excess turbine engine components.
Ytterbium	General applications for ytterbium include dopants for solid-state lasers, radiation source for mobile x-ray machines, night vision technology, fiber optic amplifier, high-energy lasers, and as an optical coating for infrared earth sensor lenses (ytterbium fluoride). U.S. consumption of ytterbium is unknown. However, annual production of ytterbium worldwide is about 50 metric tons. Known U.S. reserves of ytterbium are about 390 metric tons. The NDS Program did not find a net shortfall of ytterbium in the 2015 Base Case National Emergency Planning Assumptions. However, the concerns raised by the NSS deserve further study. The NDS Program would recommend stockpiling in the event that research uncovered a potential net shortfall for ytterbium.

Support for Future Studies: Data, Collaboration and Analysis

A strategic and critical material can be a material at different stages of its supply chain and may be an ore, compound, element or semi-processed material. Analysts at the NDS Program rely on a plethora of data tools, modeling techniques and news sources (subscriptions and open source) for information on materials of interest to the DoD. This includes pricing, demand, supply, trade, mergers and acquisitions, supply chain disruptions, end-use markets, technology trends, government policy, macroeconomic statistics and, financial data. Analysts then form analyses and assessments of the market and non-market forces shaping the global landscape for materials and their applications.

In order to bring some structure to such a vast body of data, the NDS Program has contracted with technology firm Palantir Technologies to develop a tool that integrates and synthesizes relevant data into a visual material flow. This tool is the Strategic Material Analysis & Reporting Topography (SMART). Palantir Technologies is customizing SMART to meet the NDS Program's mission.

SMART facilitates the identification, understanding and evaluation of the supply chains that support the U.S. Defense and essential civilian industrial base. The NDS Program and Oak Ridge National Laboratory (ORNL) collaborate on the development and support of SMART. Other DoD and federal agency partners provide significant input to the development of SMART and plan to use the tool to identify future materials requirements and supply chain vulnerabilities.

SMART runs on the software platform "Palantir Gotham" developed by Palantir Technologies. Palantir Gotham allows the user to aggregate and synthesize data from disparate sources based on a logic scheme called an ontology that is specific to the NDS Program's requirements.

The figure below is a schematic of the SMART ontology. As shown in the figure, the ontology involves linking supply chain nodes and documenting material flows from ore to final products. Documenting the flow of material through each processing stage from the raw material to the finished product is critical to a full understanding and assessment of supply chain risk. In keeping with the NDS Program's mission, SMART can also analyze domestic industrial capabilities by locating and documenting companies and facilities that have the ability to process and manufacture strategic and critical materials.

In the flow diagram below, SMART's ontology is applied to the rare earth element, neodymium. The NDS Program and ORNL are in the process of developing material flow diagrams for many of the materials on the Watch List. The figure highlights SMART's ability to visually display supply chains and highlight areas of concern. In the case of neodymium, SMART reveals a heavy foreign reliance at both the mine and downstream material level of the supply chain. As the schematic shows, only one domestic mine currently produces rare earth ore and refines neodymium to oxide while the production of neodymium metal mostly occurs outside the United States.

One of the many outstanding features of SMART is the ability for analysts to collaborate on material flow investigations. Any licensed user may develop and expand a material flow diagram in SMART. This collaboration facilitates future assessments of strategic and critical materials.

SMART is a customized tool for documenting and analyzing material flows and supply chains for potentially critical and strategic materials.

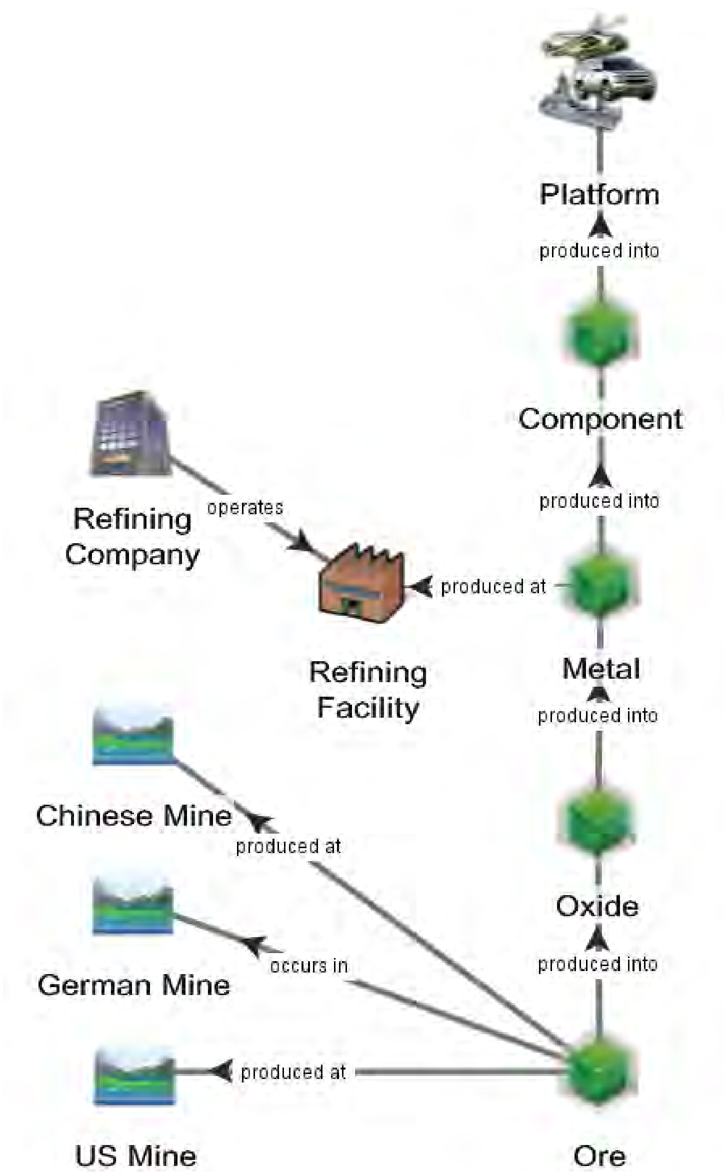

Figure 4.4.1: SMART Ontology Overview

Neodymium mines are at the bottom and final products at the top. The goal is an understanding of the United States' industrial capabilities and the required materials for defense and essential civilian needs. The neodymium material flow diagram above shows significant foreign reliance at the mine level despite the presence of one U.S. mine. U.S. mid-supply chain processing of neodymium into oxide and metal also has significant foreign reliance.

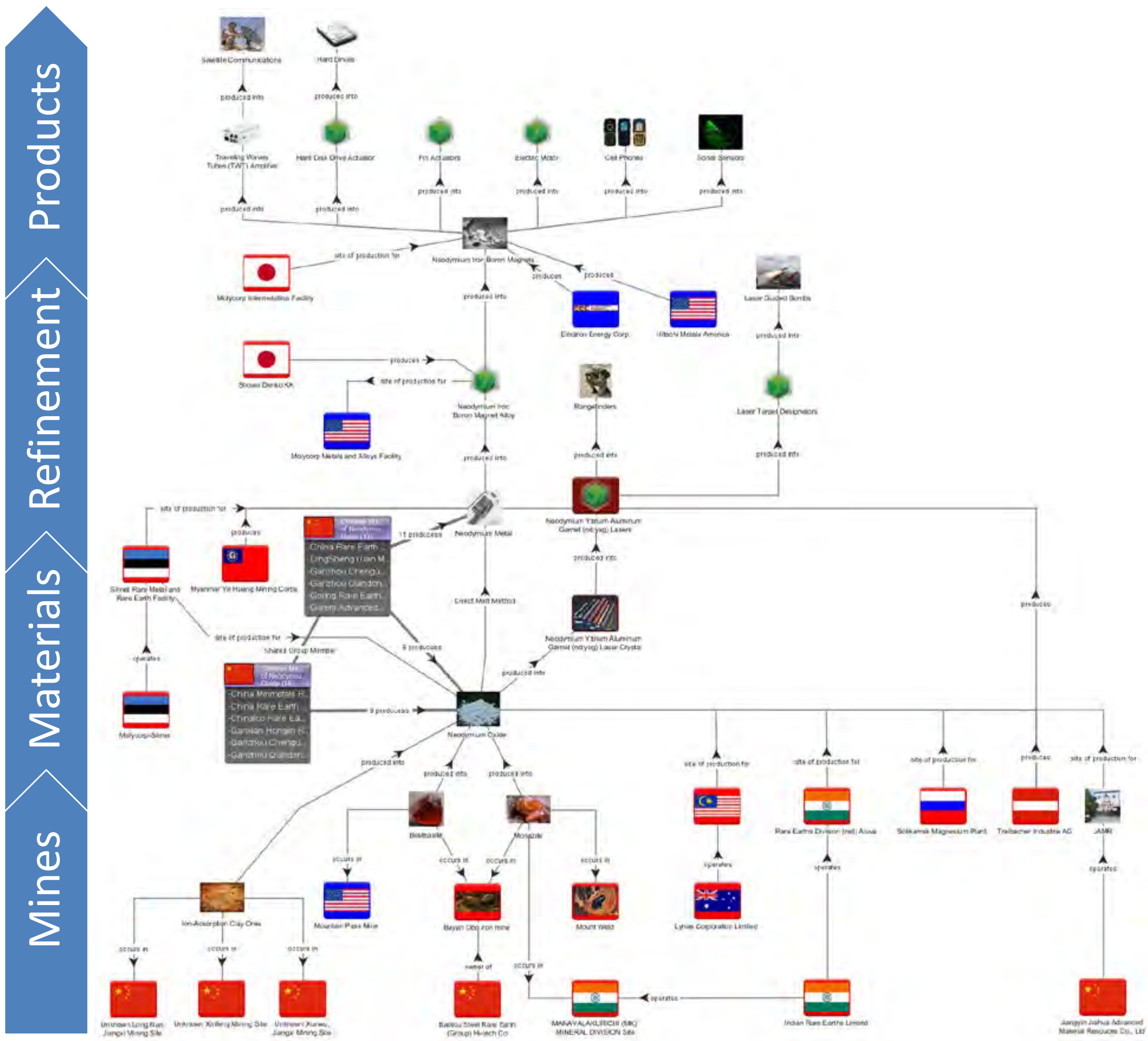

Figure 4.4.2: Example of SMART Material Flow Diagram

Appendix 1
The Stock Piling Act

Appendix 1

THE STRATEGIC AND CRITICAL MATERIALS STOCK PILING ACT (50 U.S.C. § 98 et seq.)

SEC. 1. This Act may be cited as the "Strategic and Critical Materials Stock Piling Act".

Congressional findings and declaration of purpose

SEC. 2. (a) The Congress finds that the natural resources of the United States in certain strategic and critical materials are deficient or insufficiently developed to supply the military, industrial, and essential civilian needs of the United States for national defense.

(b) It is the purpose of this Act to provide for the acquisition and retention of stocks of certain strategic and critical materials and to encourage the conservation and development of sources of such materials within the United States and thereby to decrease and to preclude, when possible, a dangerous and costly dependence by the United States upon foreign sources or a single point of failure for supplies of such materials in times of national emergency.

(c) The purpose of the National Defense Stockpile is to serve the interest of national defense only. The National Defense Stockpile is not to be used for economic or budgetary purposes.

National Defense Stockpile

SEC. 3. (a) Determination of materials; quantities. Subject to subsection (c), the President shall determine from time to time (1) which materials are strategic and critical materials for the purposes of this Act, and (2) the quality and quantity of each such material to be acquired for the purposes of this Act and the form in which each such material shall be acquired and stored. Such materials when acquired, together with the other materials described in section 4 of this Act, shall constitute and be collectively known as the National Defense Stockpile (hereinafter in this Act referred to as the "stockpile").

(b) Guidelines for exercise of Presidential authority. The President shall make the determinations required to be made under subsection (a) on the basis of the principles stated in section 2(c).

(c) Quantity change; notification to Congress.

(1) The quantity of any material to be stockpiled under this Act, as in effect on September 30, 1987, may be changed only as provided in this subsection or as otherwise provided by law enacted after December 4, 1987.

(2) The President shall notify Congress in writing of any change proposed to be made in the quantity of any material to be stockpiled. The President may make the change after the end of the 45-day period beginning on the date of the notification. The President shall include a full explanation and justification for the proposed change with the notification.

Materials constituting the National Defense Stockpile

SEC. 4. (a) Contents. The stockpile consists of the following materials:

(1) Materials acquired under this Act and contained in the national stockpile on July 29, 1979.

(2) Materials acquired under this Act after July 29, 1979.

(3) Materials in the supplemental stockpile established by section 104(b) of the Food for Peace Act [*7 USCS § 1704(b)*] (as in effect from September 21, 1959, through December 31, 1966) on July 29, 1979.

(4) Materials acquired by the United States under the provisions of section 303 of the Defense Production Act of 1950 (*50 U.S.C. App. 2093*) and transferred to the stockpile by the President pursuant to subsection (f) of such section.

(5) Materials transferred to the United States under section 663 of the Foreign Assistance Act of 1961 (*22 U.S.C. 2423*) that have been determined to be strategic and critical materials for the purposes of this Act and that are allocated by the President under subsection (b) of such section for stockpiling in the stockpile.

(6) Materials acquired by the Commodity Credit Corporation and transferred to the stockpile under section 4(h) of the Commodity Credit Corporation Charter Act (*15 U.S.C. 714b(h)*).

(7) Materials acquired by the Commodity Credit Corporation under paragraph (2) of section 103(a) of the Act entitled "An Act to provide for greater stability in agriculture; to augment the marketing and disposal of agricultural products; and for other purposes", approved August 28, 1954 (*7 U.S.C. 1743(a)*), and transferred to the stockpile under the third sentence of such section.

(8) Materials transferred to the stockpile by the President under paragraph (4) of section 103(a) of such Act of August 28, 1954 [*7 USCS § 1743(a)(4)*].

(9) Materials transferred to the stockpile under subsection (b).

(10) Materials transferred to the stockpile under subsection (c).

(b) Transfer and reimbursement. Notwithstanding any other provision of law, any material that (1) is under the control of any department or agency of the United States, (2) is determined by the head of such department or agency to be excess to its needs and responsibilities, and (3) is required for the stockpile shall be transferred to the stockpile. Any such transfer shall be made without reimbursement to such department or agency, but all costs required to effect such transfer shall be paid or reimbursed from funds appropriated to carry out this Act.

(c) Transfer and disposal.

(1) The Secretary of Energy, in consultation with the Secretary of Defense, shall transfer to the stockpile for disposal in accordance with this Act uncontaminated materials that are in the Department of Energy inventory of materials for the production of defense-related items, are excess to the requirements of the Department for that purpose, and are suitable for transfer to the stockpile and disposal through the stockpile.

(2) The Secretary of Defense shall determine whether materials are suitable for transfer to the stockpile under this subsection, are suitable for disposal through the stockpile, and are uncontaminated.

Authority for stockpile operations

SEC. 5. (a) Funds appropriated for acquisitions; proposed stockpile transactions; significant changes therein.

(1) Except for acquisitions made under the authority of paragraph (3) or (4) of section 6(a), no funds may be obligated or appropriated for acquisition of any material under this Act unless funds for such acquisition have been authorized by law. Funds appropriated for such acquisition (and for transportation and other incidental expenses related to such acquisition) shall remain available until expended, unless otherwise provided in appropriation Acts.

(2) If for any fiscal year the President proposes certain stockpile transactions in the annual materials plan submitted to Congress for that year under section 11(b) and after that plan is submitted the President proposes (or Congress requires) a significant change in any such transaction, or a significant transaction not included in such plan, no amount may be obligated or expended for such transaction during such year until the President has submitted a full statement of the proposed transaction to the appropriate committees of Congress and a period of 45 days has passed from the date of the receipt of such statement by such committees.

(b) Disposal. Except for disposals made under the authority of paragraph (3), (4), or (5) of section 6(a) or under section 7(a), no disposal may be made from the stockpile unless such disposal, including the quantity of the material to be disposed of, has been specifically authorized by law.

(c) Authorization of appropriations. There is authorized to be appropriated such sums as may be necessary to provide for the transportation, processing, refining, storage, security, maintenance, rotation, and disposal of materials contained in or acquired for the stockpile. Funds appropriated for such purposes shall remain available to carry out the purposes for which appropriated for a period of two fiscal years, if so provided in appropriation Acts.

Stockpile management

SEC. 6. (a) Presidential powers. The President shall-

(1) acquire the materials determined under section 3(a) to be strategic and critical materials;

(2) provide for the proper storage, security, and maintenance of materials in the stockpile;

(3) provide for the upgrading, refining, or processing of any material in the stockpile (notwithstanding any intermediate stockpile quantity established for such material) when necessary to convert such material into a form more suitable for storage, subsequent disposition, and immediate use in a national emergency;

(4) provide for the rotation of any material in the stockpile when necessary to prevent deterioration or technological obsolescence of such material by replacement of such material with an equivalent quantity of substantially the same material or better material;

(5) provide for the appropriate recovery of any strategic and critical materials under section 3(a) that may be available from excess materials made available for recovery purposes by other Federal agencies;

(6) subject to the notification required by subsection (d)(2), provide for the timely disposal of materials in the stockpile that (A) are excess to stockpile requirements, and (B) may cause a loss to the Government if allowed to deteriorate; and

(7) subject to the provisions of section 5(b), dispose of materials in the stockpile the disposal of which is specifically authorized by law.

(b) Federal procurement practices. Except as provided in subsections (c) and (d), acquisition of strategic and critical materials under this Act shall be made in accordance with established Federal procurement practices, and, except as provided in subsections (c) and (d) and in section 7(a), disposal of strategic and critical materials from the stockpile shall be made in accordance with the next sentence. To the maximum extent feasible--

(1) competitive procedures shall be used in the acquisition and disposal of such materials; and

(2) efforts shall be made in the acquisition and disposal of such materials to avoid undue disruption of the usual markets of producers, processors, and consumers of such materials and to protect the United States against avoidable loss.

(c) Barter; use of stockpile materials as payment for expenses of acquiring, refining, processing, or retailing materials.

(1) The President shall encourage the use of barter in the acquisition under subsection (a)(1) of strategic and critical materials for, and the disposal under subsection (a)(5) or (a)(6) of materials from, the stockpile when acquisition or disposal by barter is authorized by law and is practical and in the best interest of the United States.

(2) Materials in the stockpile (the disposition of which is authorized by paragraph (3) to finance the upgrading, refining, or processing of a material in the stockpile, or is otherwise authorized by law) shall be available for transfer at fair market value as payment for expenses (including transportation and other incidental expenses) of acquisition of materials, or of upgrading, refining, processing, or rotating materials, under this Act.

(3) Notwithstanding section 3(c) or any other provision of law, whenever the President provides under subsection (a)(3) for the upgrading, refining, or processing of a material in the stockpile to convert that material into a form more suitable for storage, subsequent disposition, and immediate use in a national emergency, the President may barter a portion of the same material (or any other material in the stockpile that is authorized for disposal) to finance that upgrading, refining, or processing.

(4) To the extent otherwise authorized by law, property owned by the United States may be bartered for materials needed for the stockpile.

(d) Waiver; notification of proposed disposal of materials.

(1) The President may waive the applicability of any provision of the first sentence of subsection (b) to any acquisition of material for, or disposal of material from, the stockpile. Whenever the President waives any such provision with respect to any such acquisition or disposal, or whenever the President determines that the application of paragraph (1) or (2) of such subsection to a particular acquisition or disposal is not feasible, the President shall notify the Committee on Armed Services of the Senate and the Committee on Armed Services of the House of Representatives in writing of the proposed acquisition or disposal at least 45 days before any

obligation of the United States is incurred in connection with such acquisition or disposal and shall include in such notification the reasons for not complying with any provision of such subsection.

(2) Materials in the stockpile may be disposed of under subsection (a)(5) only if such congressional committees are notified in writing of the proposed disposal at least 45 days before any obligation of the United States is incurred in connection with such disposal. (e) Leasehold interests in property. The President may acquire leasehold interests in property, for periods not in excess of twenty years, for storage, security, and maintenance of materials in the stockpile.

Special Presidential disposal authority

SEC. 7. (a) Materials in the stockpile may be released for use, sale, or other disposition--

(1) on the order of the President, at any time the President determines the release of such materials is required for purposes of the national defense;

(2) in time of war declared by the Congress or during a national emergency, on the order of any officer or employee of the United States designated by the President to have authority to issue disposal orders under this subsection, if such officer or employee determines that the release of such materials is required for purposes of the national defense; and

(3) on the order of the Under Secretary of Defense for Acquisition, Technology, and Logistics, if the President has designated the Under Secretary to have authority to issue release orders under this subsection and, in the case of any such order, if the Under Secretary determines that the release of such materials is required for use, manufacture, or production for purposes of national defense.

(b) Any order issued under subsection (a) shall be promptly reported by the President, or by the officer or employee issuing such order, in writing, to the Committee on Armed Services of the Senate and the Committee on Armed Services of the House of Representatives.

Materials development and research

SEC. 8. (a) Development, mining, preparation, treatment, and utilization of ores and other mineral substances.

(1) The President shall make scientific, technologic, and economic investigations concerning the development, mining, preparation, treatment, and utilization of ores and other mineral substances that (A) are found in the United States, or in its territories or possessions, (B) are essential to the national defense, industrial, and essential civilian needs of the United States, and (C) are found in known domestic sources in inadequate quantities or grades.

(2) Such investigations shall be carried out in order to--

(A) determine and develop new domestic sources of supply of such ores and mineral substances;

(B) devise new methods for the treatment and utilization of lower grade reserves of such ores and mineral substances; and

(C) develop substitutes for such essential ores and mineral products.

(3) Investigations under paragraph (1) may be carried out on public lands and, with the consent of the owner, on privately owned lands for the purpose of exploring and determining the extent and quality of deposits of such minerals, the most suitable methods of mining and beneficiating such minerals, and the cost at which the minerals or metals may be produced.

(b) Development of sources of supplies of agricultural commodities for manufacture of materials. The President shall make scientific, technologic, and economic investigations of the feasibility of developing domestic sources of supplies of any agricultural material or for using agricultural commodities for the manufacture of any material determined pursuant to section 3(a) of this Act to be a strategic and critical material or substitutes therefor.

(c) Development of sources of supplies of other materials; development of use of alternative methods for refining or processing materials in stockpile. The President shall make scientific, technologic, and economic investigations concerning the feasibility of--

(1) developing domestic sources of supply of materials (other than materials referred to in subsections (a) and (b)) determined pursuant to section 3(a) to be strategic and critical materials; and

(2) developing or using alternative methods for the refining or processing of a material in the stockpile so as to convert such material into a form more suitable for use during an emergency or for storage.

(d) Grants and contracts to encourage conservation of strategic and critical materials. The President shall encourage the conservation of domestic sources of any material determined pursuant to section 3(a) to be a strategic and critical material by making grants or awarding contracts for research regarding the development of--

(1) substitutes for such material; or

(2) more efficient methods of production or use of such material.

National Defense Stockpile Transaction Fund

SEC. 9. (a) Establishment. There is established in the Treasury of the United States a separate fund to be known as the National Defense Stockpile Transaction Fund (hereinafter in this section referred to as the "fund").

(b) Fund operations.

(1) All moneys received from the sale of materials in the stockpile under paragraphs (5) and (6) of section 6(a) shall be covered into the fund.

(2) Subject to section 5(a)(1)], moneys covered into the fund under paragraph (1) are hereby made available (subject to such limitations as may be provided in appropriation Acts) for the following purposes:

(A) The acquisition, maintenance, and disposal of strategic and critical materials under section 6(a) *a).*

(B) Transportation, storage, and other incidental expenses related to such acquisition, maintenance, and disposal.

(C) Development of current specifications of stockpile materials and the upgrading of existing stockpile materials to meet current specifications (including transportation, when economical, related to such upgrading).

(D) Encouraging the appropriate conservation of strategic and critical materials.

(E) Testing and quality studies of stockpile materials.

(F) Studying future material and mobilization requirements for the stockpile.

(G) Activities authorized under section 15.

(H) Contracting under competitive procedures for materials development and research to--

(i) improve the quality and availability of materials stockpiled from time to time in the stockpile; and

(ii) develop new materials for the stockpile.

(I) Improvement or rehabilitation of facilities, structures, and infrastructure needed to maintain the integrity of stockpile materials.

(J) Disposal of hazardous materials that are stored in the stockpile and authorized for disposal by law.

(K) Performance of environmental remediation, restoration, waste management, or compliance activities at locations of the stockpile that are required under a Federal law or are undertaken by the Government under an administrative decision or negotiated agreement.

(L) Pay of employees of the National Defense Stockpile program.

(M) Other expenses of the National Defense Stockpile program.

(3) Moneys in the fund shall remain available until expended.

(c) Moneys received from the sale of materials being rotated or disposed of. All moneys received from the sale of materials being rotated under the provisions of section 6(a)(4) or disposed of under section 7(a) shall be covered into the fund and shall be available only for the acquisition of replacement materials.

(d) Effect of bartering. If, during a fiscal year, the National Defense Stockpile Manager barters materials in the stockpile for the purpose of acquiring, upgrading, refining, or processing other materials (or for services directly related to that purpose), the contract value of the materials so bartered shall--

(1) be applied toward the total value of materials that are authorized to be disposed of from the stockpile during that fiscal year;

(2) be treated as an acquisition for purposes of satisfying any requirement imposed on the National Defense Stockpile Manager to enter into obligations during that fiscal year under subsection (b)(2); and

(3) not increase or decrease the balance in the fund.

Advisory committees

SEC. 10. (a) Membership. The President may appoint advisory committees composed of individuals with expertise relating to materials in the stockpile or with expertise in stockpile management to advise the President with respect to the acquisition, transportation, processing, refining, storage, security, maintenance, rotation, and disposal of such materials under this Act.

(b) Expenses. Each member of an advisory committee established under subsection (a) while serving on the business of the advisory committee away from such member's home or regular place of business shall be allowed travel expenses, including per diem in lieu of subsistence, as authorized by section 5703 of title 5, United States Code, for persons intermittently employed in the Government service.

(c) Market Impact Committee.

(1) The President shall appoint a Market Impact Committee composed of representatives from the Department of Agriculture, the Department of Commerce, the Department of Defense, the Department of Energy, the Department of the Interior, the Department of State, the Department of the Treasury, and the Federal Emergency Management Agency, and such other persons as the President considers appropriate. The representatives from the Department of Commerce and the Department of State shall be Cochairmen of the Committee.

(2) The Committee shall advise the National Defense Stockpile Manager on the projected domestic and foreign economic effects of all acquisitions and disposals of materials from the stockpile that are proposed to be included in the annual materials plan submitted to Congress under section 11(b), or in any revision of such plan, and shall submit to the manager the Committee's recommendations regarding those acquisitions and disposals.

(3) The annual materials plan or the revision of such plan, as the case may be, shall contain--

(A) the views of the Committee on the projected domestic and foreign economic effects of all acquisitions and disposals of materials from the stockpile;

(B) the recommendations submitted by the Committee under paragraph (2); and

(C) for each acquisition or disposal provided for in the plan or revision that is inconsistent with a recommendation of the Committee, a justification for the acquisition or disposal.

(4) In developing recommendations for the National Defense Stockpile Manager under paragraph (2), the Committee shall consult from time to time with representatives of producers, processors, and consumers of the types of materials stored in the stockpile.

Reports to Congress

SEC. 11. (a) Not later than January 15 of each year, the President shall submit to the Congress an annual written report detailing operations under this Act. Each such report shall include--

(1) information with respect to foreign and domestic purchases of materials during the preceding fiscal year;

(2) information with respect to the acquisition and disposal of materials under this Act by barter, as provided for in section 6(c) of this Act during such fiscal year;

(3) information with respect to the activities by the Stockpile Manager to encourage the conservation, substitution, and development of strategic and critical materials within the United States;

(4) information with respect to the research and development activities conducted under sections 2 and 8;

(5) a statement and explanation of the financial status of the National Defense Stockpile Transaction Fund and the anticipated appropriations to be made to the fund, and obligations to be made from the fund, during the current fiscal year; and

(6) such other pertinent information on the administration of this Act as will enable the Congress to evaluate the effectiveness of the program provided for under this Act and to determine the need for additional legislation.

(b) (1) Not later than February 15 of each year, the President shall submit to the appropriate committees of the Congress a report containing an annual materials plan for the operation of the stockpile during the next fiscal year and the succeeding four fiscal years.

(2) Each such report shall include details of all planned expenditures from the National Defense Stockpile Transaction Fund during such period (including expenditures to be made from appropriations from the general fund of the Treasury) and of anticipated receipts from proposed disposals of stockpile materials during such period. Each such report shall also contain details regarding the materials development and research projects to be conducted under section 9(b)(2)(G) during the fiscal years covered by the report. With respect to each development and research project, the report shall specify the amount planned to be expended from the fund, the material intended to be developed, the potential military or defense industrial applications for that material, and the development and research methodologies to be used.

(3) Any proposed expenditure or disposal detailed in the annual materials plan for any such fiscal year, and any expenditure or disposal proposed in connection with any transaction submitted for such fiscal year to the appropriate committees of Congress pursuant to section 5(a)(2) that is not obligated or executed in that fiscal year may not be obligated or executed until such proposed expenditure or disposal is resubmitted in a subsequent annual materials plan or is resubmitted to the appropriate committees of Congress in accordance with section 5(a)(2), as appropriate.

Definitions

SEC. 12.For the purposes of this Act:

(1) The term "strategic and critical materials" means materials that (A) would be needed to supply the military, industrial, and essential civilian needs of the United States during a national emergency, and (B) are not found or produced in the United States in sufficient quantities to meet such need.

(2) The term "national emergency" means a general declaration of emergency with respect to the national defense made by the President or by the Congress.

Importation of strategic and critical materials

SEC. 13.The President may not prohibit or regulate the importation into the United States of any material determined to be strategic and critical pursuant to the provisions of this Act, if such material is the product of any foreign country or area not listed in general note 3(b) of the Harmonized Tariff Schedule of the United States (*19 USC 1202*), for so long as the importation into the United States of material of that kind which is the product of a country or area listed in such general note is not prohibited by any provision of law.

Biennial report on stockpile requirements

SEC. 14. (a) In general. Not later than January 15 of every other year, the Secretary of Defense shall submit to Congress a report on stockpile requirements. Each such report shall include--

(1) the Secretary's recommendations with respect to stockpile requirements; and

(2) the matters required under subsection (b).

(b) National emergency planning assumptions. Each report under this section shall set forth the national emergency planning assumptions used by the Secretary in making the Secretary's recommendations under subsection (a)(1) with respect to stockpile requirements. The Secretary shall base the national emergency planning assumptions on a military conflict scenario consistent with the scenario used by the Secretary in budgeting and defense planning purposes. The assumptions to be set forth include assumptions relating to each of the following:

(1) The length and intensity of the assumed military conflict.

(2) The military force structure to be mobilized.

(3) The losses anticipated from enemy action.

(4) The military, industrial, and essential civilian requirements to support the national emergency.

(5) The availability of supplies of strategic and critical materials from foreign sources during the mobilization period, the military conflict, and the subsequent period of replenishment, taking into consideration possible shipping losses.

(6) The domestic production of strategic and critical materials during the mobilization period, the military conflict, and the subsequent period of replenishment, taking into consideration possible shipping losses.

(7) Civilian austerity measures required during the mobilization period and military conflict.

(c) Period within which to replace or replenish materials. The stockpile requirements shall be based on those strategic and critical materials necessary for the United States to replenish or replace, within three years of the end of the military conflict scenario required under subsection (b), all munitions, combat support items, and weapons systems that would be required after such a military conflict.

(d) Effect of alternative mobilization periods. The Secretary shall also include in each report under this section an examination of the effect that alternative mobilization periods under the military conflict scenario required under subsection (b), as well as a range of other military conflict scenarios addressing potentially more serious threats to national security, would have on the Secretary's recommendations under subsection (a)(1) with respect to stockpile requirements.

(e) Plans of President. The President shall submit with each report under this section a statement of the plans of the President for meeting the recommendations of the Secretary set forth in the report.

Development of domestic sources

SEC. 15. (a) Purchase of materials of domestic origin; processing of materials in domestic facilities. Subject to subsection (c) and to the extent the President determines such action is required for the national defense, the President shall encourage the development and appropriate conservation of domestic sources for materials determined pursuant to section 3(a) to be strategic and critical materials--

(1) by purchasing, or making a commitment to purchase, strategic and critical materials of domestic origin when such materials are needed for the stockpile; and

(2) by contracting with domestic facilities, or making a commitment to contract with domestic facilities, for the processing or refining of strategic and critical materials in the stockpile when processing or refining is necessary to convert such materials into a form more suitable for storage and subsequent disposition.

(b) Terms and conditions of contracts or commitments. A contract or commitment made under subsection (a) may not exceed five years from the date of the contract or commitment. Such purchases and commitments to purchase may be made for such quantities and on such terms and conditions, including advance payments, as the President considers to be necessary.

(c) Proposed transactions included in annual materials plan; availability of funds.

(1) Descriptions of proposed transactions under subsection (a) shall be included in the appropriate annual materials plan submitted to Congress under section 11(b). Changes to any such transaction, or the addition of a transaction not included in such plan, shall be made in the manner provided by section 5(a)(2).

(2) The authority of the President to enter into obligations under this section is effective for any fiscal year only to the extent that funds in the National Defense Stockpile Transaction Fund are adequate to meet such obligations. Payments required to be as a result of obligations incurred under this section shall be made from amounts in the fund.

(d) Transportation and other incidental expenses. The authority of the President under subsection (a) includes the authority to pay--

(1) the expenses of transporting materials; and

(2) other incidental expenses related to carrying out such subsection.

(e) Reports. The President shall include in the reports required under section 11(a) information with respect to activities conducted under this section.

National Defense Stockpile Manager

SEC. 16. (a) Appointment. The President shall designate a single Federal office to have responsibility for performing the functions of the President under this Act, other than under sections 7(a)(1) and 13. The office designated shall be one to which appointment is made by the President, by and with the advice and consent of the Senate.

(b) Title of designated officer. The individual holding the office designated by the President under subsection (a) shall be known for purposes of functions under this Act as the "National Defense Stockpile Manager".

(c) Delegation of functions. The President may delegate functions of the President under this Act (other than under sections 7(a)(1) and 13) only to the National Defense Stockpile Manager. Any such delegation made by the President shall remain in effect until specifically revoked by law or Executive order. The President may not delegate functions of the President under sections 7(a)(1) and 13.

Appendix 2
Base Case Initial Shortfall Methods and Analysis

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Appendix 2a. Modeling Method Selection Process

Materials Raised to the Attention of the NDS Program

In support of the National Defense Stockpile (NDS Program) requirements process, Defense Logistics Agency Strategic Materials (the NDS Program manager) continuously monitors supply chains of materials that are important to specific Department of Defense (DoD) defense systems and weapons platforms. To assist with the 2015 NDS Program material selection process, Defense Logistics Agency Strategic Materials issued a formal survey to various components within DoD as well as to entities outside of DoD (e.g., academia and industry). The intent of this process was to identify materials that the survey respondents consider essential for U. S. defense and civilian demands and whose supplies could possibly be at risk in a future national emergency.

RAMF-SM modeling begins with the initial selection of materials. Materials for study are selected by the NDS Program based upon the results of the Filter Process described in Chapter 2. In addition, the NDS Program bases its selections on the recommendations from a number of defense and non-defense organizations. These include DoD components, the Executive Branch, Congress, subject matter experts (SMEs) from Federally Funded Research and Development Centers (FFRDCs), industry, academia and from other interested parties. Criteria for selecting specific materials for study will normally include evidence of potential shortfalls of the material in relevant planning scenarios or other evidence of "weak links" in supply chains.

In addition to evaluating recommendations from other organizations, the NDS Program explicitly obtains nominees for materials to include in the Requirements Report. This was accomplished by letter sent on behalf of the DoD Stockpile Manager to the various DoD components and other interested parties.

Inclusion of a material nominee in the assessment process also depended upon the availability of sufficient and relevant data regarding supply and demand. If a material does not exhibit a potential shortfall at the upstream raw material level it should be excluded from consideration in the downstream supply chain assessment. Some materials may be available in sufficient quantities at the upstream level, yet not be usable by U.S. industry at the downstream level due to production capacity gaps at those downstream nodes. The NDS Program must, therefore, exercise care in setting the criteria for inclusion or exclusion of a material from the study cycle.

Materials Studied in the Report

As a result of the processes explained above, 92 materials were included for the 2015 NDS Program report cycle. The complete list of study materials is shown in Table A2a.1.

Table A2a.1 Materials Studied	
Number	**Material Name**
1	1,2,4-Butanetriol
2	1,3,5 Trichlorobenzene
3	Aluminum lithium alloys
4	Aluminum oxide, fused crude
5	Ammonium perchlorate
6	Antimony
7	Beryl ore
8	Beryllium copper master alloy
9	Beryllium metal
10	Bismuth
11	Boron
12	Boron carbide (one type)
13	Borosilicate floated glass
14	Cadmium zinc telluride
15 - 27	Carbon fiber, PAN-based (13 types)
28	Carbon fiber, rayon-based aerospace grade
29	Cerium
30	Chlorosulfonated polyethylene (CSM)
31	Chromium ferro (Ferrochromium)
32	Chromium metal
33	Cobalt
34	Dysprosium
35	Erbium
36	Europium
37	Fluorspar, acid grade
38	Fluorspar, metallurgical grade
39	Gadolinium
40	Gallium
41	Germanium
42	Graphite
43	Hydrazine
44	Hydrofluorocarbon (one type)
45	Hydroxyl-terminated polybutadiene (HTPB)
46	Indium
47	Iridium

Table A2a.1 Materials Studied	
Number	**Material Name**
48	Lanthanum
49	Lead
50	Lithium
51	Magnesium
52	Manganese ferro (Ferromanganese)
53	Manganese metal, electrolytic
54	Manganese ore, chemical/metal Grade
55-58	Minor rare earths (Ho Tm Yb Lu)
59	Neodymium
60	Nickel
61	Niobium (Columbium)
62	Nitrocellulose
63	Nitrogen tetroxide
64	Palladium
65	Platinum
66	Polypropylene fiber (one type)
67	Praseodymium
68	Quartz crystal, synthetic
69	Rhenium
70	Rubber, natural
71	Samarium
72-75	Scandium (4 types)
76	S-Glass (one type)
77	Silicon carbide
78	Silicon carbide fiber (one type)
79	Strontium
80	Tantalum
81	Tellurium
82	Terbium
83	Tin
84	Tourmaline
85	Triaminotrinitrobenzene (TATB)
86	Tungsten
86-87	Tungsten-rhenium alloy (2 types)
88	Ultrahigh molecular weight polyethylene fiber
89	Vanadium
90	Yttrium
91	Yttrium oxide (high purity)
92	Zinc

List of Materials Modeled in RAMF-SM

Of the 92 materials in the report, 79 materials received either full or partial RAMF-SM modeling. These materials appear in Table A2a.2.

Table A2a.2 Materials Modeled in RAMF-SM	
Number	**Material Name**
1	Aluminum lithium alloys
2	Aluminum oxide, fused crude
3	Antimony
4	Beryl ore
5	Beryllium copper master alloy
6	Beryllium metal
7	Bismuth
8	Boron
9	Boron carbide (one type)
10-22	Carbon fiber, PAN-based (13 types)
23	Cerium
24	Chlorosulfonated polyethylene (CSM)
25	Chromium ferro (Ferrochromium)
26	Chromium metal
27	Cobalt
28	Dysprosium
29	Erbium
30	Europium
31	Fluorspar, acid grade
32	Fluorspar, metallurgical grade
33	Gadolinium
34	Gallium
35	Germanium
36	Graphite
37	Hydrofluorocarbon (one type)
38	Indium
39	Iridium
40	Lanthanum
41	Lead
42	Lithium
43	Magnesium
44	Manganese ferro (Ferromanganese)
45	Manganese metal, electrolytic
46	Manganese ore, chemical/metal Grade

Table A2a.2 Materials Modeled in RAMF-SM	
Number	**Material Name**
47	Minor rare earths (Ho Tm Yb Lu)
48	Neodymium
49	Nickel
50	Niobium (Columbium)
51	Palladium
52	Platinum
53	Polypropylene fiber (one type)
54	Praseodymium
55	Quartz crystal, synthetic
56	Rhenium
57	Rubber, natural
58	Samarium
59-62	Scandium (4 types)
63	S-Glass (one type)
64	Silicon carbide
65-67	Silicon carbide fiber, multifilament (3 types)
68	Strontium
69	Tantalum
70	Tellurium
71	Terbium
72	Tin
73	Tungsten
74-75	Tungsten-Rhenium alloy (2 types)
76	Vanadium
77	Yttrium
78	Yttrium oxide (high purity)
79	Zinc

List of Materials Modeled by Bottom-Up or Other Method

There were 13 materials of concern that did not meet the minimal data requirements discussed above. Therefore, these materials could not be assessed using RAMF-SM. Rather these materials were evaluated using either the bottom-up or other research methods. These materials appear in Table A2a.3 below.

Table A2a.3. Materials Modeled by Bottom-Up or Other Method	
Number	**Material**
1	1,2,4-Butanetriol
2	1,3,5 Trichlorobenzene
3	Ammonium perchlorate
4	Borosilicate floated glass
5	Cadmium zinc telluride
6	Carbon fiber, rayon-based aerospace grade
7	Hydrazine
8	Hydroxyl-terminated polybutadiene (HTPB)
9	Nitrocellulose
10	Nitrogen tetroxide
11	Tourmaline
12	Triaminotrinitrobenzene (TATB)
13	Ultrahigh molecular weight polyethylene (UHMWPE) fiber

Appendix 2b. RAMF-SM Models and Key Variables

In preparing the National Defense Stockpile (NDS Program) Report to Congress, the Defense Logistics Agency Strategic Materials uses a suite of modeling and simulation tools known as the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM). The RAMF-SM method is also referred to as the "top-down" method in this report.

This methodology comprises Sub-steps 2A, 2B, and 2C of the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM). Additional description of the Sub-step 2 methodology is available, at varying levels of detail, and can be provided upon request. The basic methodology is consistent with those used in previous Department of Defense (DoD) Reports on National Defense Stockpile (NDS Program) Requirements.

Overview and Taxonomies of Demand

The RAMF-SM process objective is to compute shortfalls of materials in a national emergency and does this by comparing the available supply of materials against the demand for them. Available supply is computed by assessing production and production capacity by country. The computation for demands for materials requires a multi-step process. Specifically, the analysis starts from estimating a dynamic general equilibrium model representing the U.S. economy on both the aggregate level and industry level. Key macro-economic and industry-level variables, expressed in constant dollars, are extracted from the forecast. Industry-level variables obtained from the economic model, which capture economy-wide output requirements for goods and services, are viewed as benchmarks for industrial demands. Demands for materials are then derived from these industrial demands. Defense demands in a military scenario are separately incorporated into the process.

In particular, the NDS Program modeling methodology considers three broad categories of demands:

1. Demand for weapons in a military scenario, expressed in numbers of weapons or thousands of dollars (dollars are deflated to a constant year);

2. Demand for industrial output of goods and services, expressed in millions of dollars (deflated to a constant year); and

3. Demand for materials, expressed in units (e.g., tons) of material. Dollar valuations of material amounts are computed for use in output reports.

The models used in the analysis convert demand from the first category to the second, and then from the second category to the third. A supply or inventory in each category is also considered. All demands and supplies are time-phased streams, i.e., demand and supply estimates are computed for each month or year of the Base Case. Earlier demands cannot be offset by supplies that become available later. Supplies are not "perishable." That is, earlier supplies can be used to offset later demands.

There is also taxonomy of demand in terms of general economic sector: military, "industrial" or emergency investment,[13] and civilian. These sectors have formal definitions, as follows:

- *Military Sector*: The military sector includes military goods required during the emergency. This sector also includes a portion of the materials needed for replacement parts and equipment for existing government-owned industrial facilities, and new plant and equipment for government-owned facilities required in the manufacture of military goods if production occurred at normal (non-emergency) rates. The other two sectors include the additional new plant and equipment needed to produce at levels sufficient to meet emergency military demands.
- *Industrial Sector*: The industrial sector covers the construction of new plants and/or the manufacture of new equipment in the private sphere to overcome bottlenecks caused by accelerated production during a national security emergency. These bottlenecks are estimated by comparing defense-related and essential civilian requirements to the emergency operating capacity of existing plant and equipment. (In practice, this sector may be thought of most appropriately as the "emergency investment" sector.)
- *Essential Civilian Sector*: The essential civilian sector includes goods and services for general civilian use, excluding those considered nonessential for stockpile purposes. This sector includes a portion of the replacement parts and equipment for existing industrial facilities and new plant and equipment required in the manufacture of these goods if production occurred at normal (non-emergency) rates.

Military demand can be divided into ongoing (steady-state) military demand and "extraordinary" military demand associated with a conflict scenario. The models keep track of separate demand totals for each category.

[13] The term "industrial demand" is often used to refer to demands for goods and services in general, i.e., the demand for output of industries. But at times, it is used to refer to emergency investment demand specifically. The meaning should be clear from the context.

General Outline of the Modeling Process

The analysis is based on the following framework:

1. A scenario for a military situation is specified. This scenario might involve a long mobilization period culminating in conflict, or, as in the 2015 NDS Program Base Case (and all recent NDS Program Requirements studies), it might be a regeneration scenario. In a regeneration scenario, weapons and supplies lost in a conflict are rebuilt over a period of time following the conflict.[14] By suitably setting certain inputs, it is also possible to model some kind of ongoing, steady-state demand for weapons, or to model a steady-state case with no extraordinary total military demand.

2. This military situation gives rise to an extraordinary military demand for weapons, ammunition, and combat support material. Inventory (if it is appropriate to model it) is applied to reduce this demand.

3. The industrial outputs required to make these military items (net of inventory) are computed. As a result, the extraordinary military demand induces a demand on U.S. industry, possibly creating imbalances in the U.S. economy.

4. To the extraordinary military demand on industry, civilian and regular (base) military demands are added. The models then compare the industrial demand against supply. Supply includes net imports (i.e., imports minus exports). Shortfalls in industrial output, if any, are computed. The civilian demands, base military demands, imports, and exports can be multiplied by adjustment factors to reflect more accurately the situation being modeled. In particular, the civilian demands can be set to only include the portion of civilian demand deemed essential. Goods and services needed to repair homeland damage, while technically part of the extraordinary military demand, are usually included in the input files for base military and/or civilian demand.

5. If new plants and facilities are built, the additional output they produce can ameliorate some or all of the excess industrial demand. The analysis models this process. However, the goods and services required to build these plants and facilities become an additional source of demand. In the context of the study, this additional demand is referred to as the emergency investment demand. It refers only to the investment in plants and facilities necessary to address the extraordinary military demand. Spending for normal steady-state investment is included in the base military and civilian demand estimates.

[14] Current law mandates that this regeneration occur within three years of the end of the military conflict scenario.

6. The total demand on industry (i.e., extraordinary military plus base military plus civilian plus emergency investment, minus net imports) induces a demand for materials. This can be thought of as the materials required to produce or generate the goods and services.

7. Available material supplies, i.e., U.S. and foreign, are computed. Initial amounts of foreign supply might be subject to a number of different decrement factors, based on the particulars of the emergency scenario (see Section G, below). The available supply is the supply that the United States can use after all relevant decrement factors have been applied.

8. The demands for materials are compared against the available material supplies, in a time phased manner. Shortfalls are computed and noted.

The following sections provide some more explanation concerning certain portions of the above steps. As noted earlier, detailed descriptions of the modeling process can be provided upon request.

Computation of Industrial Demands

The civilian industrial demands and base military industrial demands are computed by translating the Council of Economic Advisors' (CEA's) long-range economic forecast into output requirements for the specific industry sectors. Two economic models, Long-term Inter-industry Forecasting Tool (LIFT) and Inter-industry Large-scale Integrated and Dynamic Model (ILIAD), developed by the Inter-industry Forecasting Project at the University of Maryland, are employed for the computation. These models have the unique capability to systematically decompose aggregate economic variables into the corresponding industry-level output requirements, which serves as benchmarks for industrial demands.

The LIFT model is a dynamic general equilibrium representation of the U.S. economy. LIFT forecasts gross domestic product (GDP) and its major components and derives expenditures of 83 consumer products and services, 66 types of investment expenditures, 25 types of construction expenditures, and 25 types of defense consumption and investment. It then calculates output requirements for each of the 110 production sectors; these requirements sum up to the above corresponding expenditures. LIFT also computes time-varying input-output matrices describing the inter-relationships between the 110 production sectors, that is, what these sectors must buy from one another in order to make their products. The ILIAD model further dissects the economy into 360 production sectors and computes the corresponding time-varying input-output matrices, allowing calculations and forecasts of output requirements for each sector.

The inputs to the economic models are calibrated to match the CEA macroeconomic forecast and project the industry output requirements. This CEA forecast is, essentially, a peacetime, or steady-state, forecast. Industry-level output requirements are viewed as benchmarks for industrial demands. The forecast is then modified to reflect government specifications regarding what civilian demands should be considered essential for stockpiling purposes. The detail in these models enables DoD to discriminate among various types of demands in specifying what is essential. The input-output matrices in these models are also used to determine additional output requirements generated by the assumed military conflict.

FORCEMOB

FORCEMOB stands for Forces Mobilization Model. FORCEMOB is used to compute and organize the demands for industrial output (i.e., demands for goods and services). FORCEMOB is also used for time-phased force requirements. FORCEMOB has three main parts:

1. Computation of the industrial output needed to manufacture replacements for the weapons lost and munitions expended in the conflict scenario;

2. Adjustment of the industry-related quantities computed by the LIFT and ILIAD models;

3. Computation of emergency investment demand.

All demands are time-phased streams. FORCEMOB keeps track of time by month; its outputs are eventually aggregated into quarterly or annual data. The three parts of FORCEMOB are discussed in the paragraphs below.

1. A scenario for a military situation is specified. This scenario might involve a long mobilization period culminating in conflict, or it might be a regeneration scenario. This specified military situation gives rise to an extraordinary military demand for weapons, ammunition, and combat support material. The time-phased demands for these force requirements are inputs to FORCEMOB. FORCEMOB then applies a data set that determines the industrial outputs required to make these military items. The manufacture of weapons occurs over a lead time (which can vary by weapon type), and some amount of industrial contribution is required at each month of the lead time. The result is a time-phased set of industrial demands.

2. The LIFT and ILIAD models have computed the essential civilian demands (which might include requirements for repairing damage caused by attacks on the

homeland) and base military demands. LIFT and ILIAD have also computed imports, exports, and supply (output). This information is read into FORCEMOB. FORCEMOB can then apply user-supplied adjustment factors to these values that are in concordance with specific characteristics of the conflict scenario. For example, exports might be decremented because more industrial output is needed domestically during the conflict. Imports might be decremented to reflect unreliability of foreign countries affected by the conflict.

3. The extraordinary military demand might create an imbalance in the economy, and existing industrial output (plus net imports) might be insufficient to cover the increased demand, even if industry produces at emergency operating capacity levels. If new plants and facilities are built, the additional output they produce might ameliorate some or all of the excess industrial demand. However, the goods and services required to build these plants and facilities become an additional source of demand, referred to as the emergency investment demand. FORCEMOB computes the emergency investment demand, using economic data on the industrial contributions required to build new facilities.

FORCEMOB can produce many informative reports about various subsets of its data and output. The main output report presents demands on industry, organized by industry sector and year or quarter, for each of the following categories:

- Military demand associated with the conflict scenario
- Base military demand
- Essential civilian demand
- Emergency investment demand
- Imports
- Exports

A demand value is shown for each combination of industry sector (360), time period, and category. This report is read by the computer programs that perform Sub-step 2B of RAMF-SM, the computation of material demands.

From Demands for Goods and Services to Demands for Materials

For most of the materials studied (72 of the 85), the material requirements are estimated using indices called material consumption ratios (MCRs). These ratios indicate the quantity of material (expressed in mass units, such as tons) that are consumed in the production of goods and services in each particular production sector, per billion dollars of economic output in that sector. That is, for each combination of material (72) and production sector (360), an MCR is computed. The MCR represents the amount of material needed for the given sector to produce a billion dollars (in constant-year dollars) worth of its output.

The dollar amounts of demands for goods and services computed via the economic modeling are multiplied by the MCRs to yield amounts of materials needed to satisfy these demands. Separate totals are kept track of for military, emergency investment, and civilian demands, for each material and year of the four-year Base Case. At this point, base military and extraordinary military demands are added together to yield a total defense demand amount.

The MCR methodology assumes that material usage is apportioned between civilian and defense uses in accordance with the underlying economic demand data for the corresponding industry sectors. In these data, civilian demands are much, much bigger than defense demands. There are some highly specialized materials with intensive military use where the MCR methodology would underestimate defense usage. For these materials, an alternate methodology was developed, in which subject matter experts specify a fraction of military use for each material application. These explicit military proportions allow the projected military and civilian material demands to be consistent with actual usage patterns. The alternate methodology was used for a limited set of materials (13 materials) designated by the Defense Logistics Agency Strategic Materials.

Input Data and Basic Terminology of MCRs

The MCR calculation process is performed separately for each material. In the example below, assume that one material is under consideration.

A distinction is made between steady-state conditions (which might involve some amount of ongoing operations) and Base Case conditions. Base Case conditions are those involving a national emergency scenario. Reference period refers to a recent year or set of years where historical data are available. For this report, the reference period is 2010 through 2012. Quantities defined “in the reference period” refer to average annual amounts over the years in the reference period, under steady-state conditions. The Base Case is the four-year period (2017 through 2020 for this report) that includes a one-year national emergency, and is postulated to start several years after the reference period.

The process requires the following input data:

- Inputs concerning the material.
- Amount of material (measured in mass units, such as tons) consumed by the United States in the reference period (average annual) under peacetime conditions.
- List of application areas for which the material is used.
- Proportion of the consumption amount that is used in each given application area (in the United States, in the reference period). The proportions must sum to 1.0.

For each application area, a list of industry sectors that is associated with that application area.

- Economic inputs (measured in millions of constant-year dollars).

For each industry sector

  - Output of that sector in the reference period, under peacetime conditions
  - For each year of the scenario, under the scenario conditions
    - Defense demand (in that sector), expressed in total requirements terms
    - Civilian demand, expressed in total requirements terms
    - Exports, expressed in total requirements terms
    - Imports, expressed in total requirements terms
    - Emergency Investment demand

The material-related inputs on consumption quantities and end-use applications have generally been obtained from material specialists at the Department of Commerce (DoC) or the U.S. Geological Survey (USGS). The economic inputs are generated by the INFORUM models (e.g. LIFT, ILIAD) and FORCEMOB. The link between the two sets of data is the lists of industry sectors associated with each application. These sectors are determined by an expert familiar with the industry sectors of the INFORUM models, with advice from the material specialists about the specific uses of the material in question.

This linking of material usage with industry sectors allows the construction of a modeling process that makes it possible to determine the change in demand for material that results from changes in the demand for output from a certain industry sector (as computed by the economic modeling).

Construction of the MCRs

The MCR represents the amount of material used by an industry sector in producing a billion dollars' of output. Computations are performed using reference period values under steady-state conditions. The total amount of material consumed is given. This material is apportioned among the industry sectors, by way of the application areas. That is, for each of the 360 industry sectors of the economic models, an amount of material used by that sector is computed; these amounts add up to the total consumption value. For each sector, the amount of material used by that sector is divided by the amount of that sector's output (in billions of dollars, from the economic databases) to compute the MCR. Note that a separate MCR is computed for each combination of material and industry sector. A number of these values are zero, since not all sectors use all materials. Additionally, note that the MCRs are computed from average reference period data, and do not vary by year.

Computation of Material Demands in the Scenario Period

Now turn from the reference period and steady-state conditions to the scenario period and scenario (national emergency) conditions. The economic modeling has computed, for each combination of industry sector and year of the scenario period, the various components of demand—defense, civilian, emergency investment, imports, and exports, as noted above.

Each of these components is multiplied by the MCR for that combination of material and industry sector (as stated earlier, MCRs do not vary by year of the scenario) to yield an amount of material associated with that combination of component, year, and industry sector. Net exports are amalgamated with civilian demand. The values for each component are then summed over all industry sectors to yield overall demands for the material that are associated with each component, in each given year.

Embedded Demand

The United States makes use of materials in two main ways:

1. Raw material is consumed by U.S. industry to manufacture usable finished goods (parts and end items).

2. Material is contained in imports of finished goods, or is used abroad in the production of finished goods that are then imported by the United States.

Both of these ways represent material that goes to satisfy U.S. demand, and both need to be considered in determining U.S. demand for materials. Material in the second category can be referred to as "embedded" material demand. The key parameters in determining embedded material demand are the MCRs. As stated above, the MCR specifies the amount of material (in mass units, such as tons) consumed by a given industry in producing a given dollar amount of its output. A major part of this material might end up in the output product itself, but the MCR could also include material used in necessary manufacturing machinery or material that is wasted.

Before describing how MCRs are used to compute embedded material amounts, let us review RAMF-SM's modeling of material and industrial flow.

Flows of Material and Industrial Output

Figure A2b.1 depicts the flow of material as it is modeled in RAMF-SM Step 2. To avoid making the figure too cluttered, the meanings of the flows along the various arcs are not shown. Definitions of the arc flows appear below the figure. Note that flows along arcs 1 through 4 are expressed in mass units (e.g., tons) of material, while flows along arcs 7 through 10 are expressed in millions or billions of dollars' worth of end items.

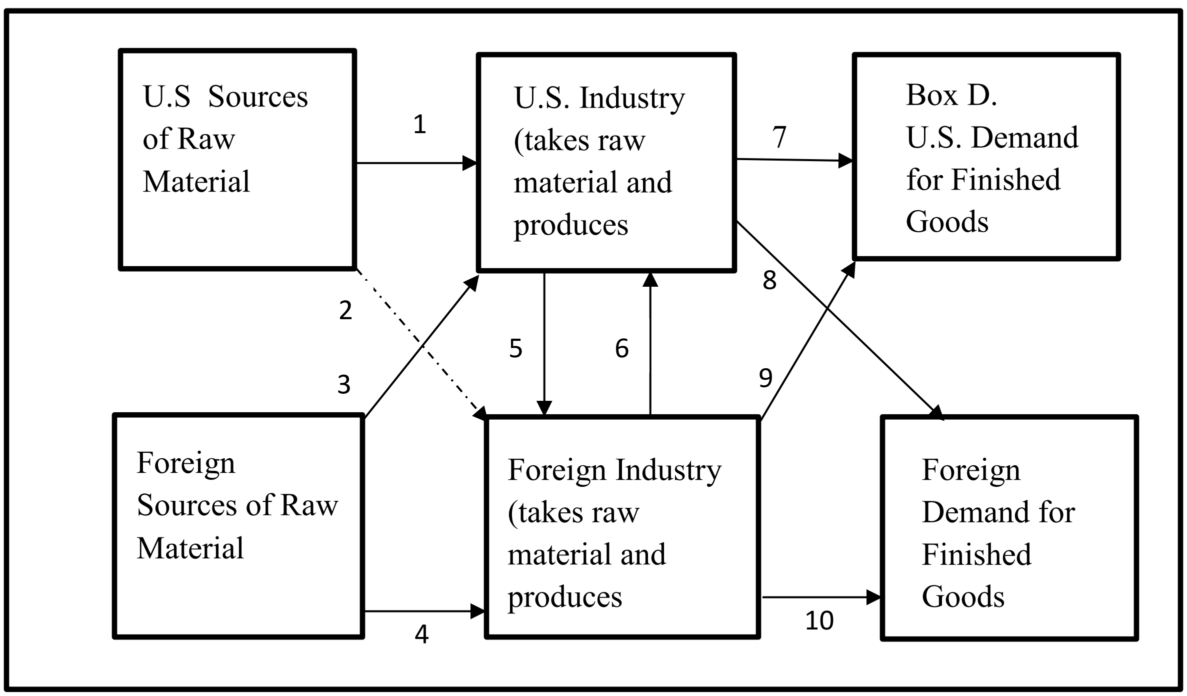


Figure A2b.1. RAMF-SM Step 2 Material and Industrial Output Flow

- Arc 1 represents U.S. raw material that is available to be used by U.S. industry. This is a key quantity for the Computation of Material Shortfalls portion of RAMF-SM, and is known in that context as U.S. supply.
- Arc 2 represents U.S. raw material that is exported to other countries. It is shown as a dashed line because in a national emergency, all U.S. supply is considered to be available to U.S. industry if needed; exports of raw material are not explicitly modeled.
- Arc 3 represents amounts of foreign raw material potentially available to the U.S. This is also a key quantity for the material shortfall computation process and is known in that context as available foreign supply. In general, the U.S. can count on getting only a certain fraction (the "market share") of foreign raw material. In a national emergency, it might get less than that because of supplier country adversary status, unreliability, and other such factors.
- Arc 4, foreign raw material that goes to foreign countries, is not explicitly modeled, but can be thought of as corresponding to material not included in the U.S. market share.
- Arcs 5 and 6, flows between U.S. and foreign industries, are included here because they happen in actuality, but they are not explicitly modeled at the aggregation level of RAMF-SM. They might play a big role in a more disaggregated model (see below).
- Arc 7 represents U.S.-manufactured finished goods that are used in the U.S., and satisfy U.S. demands.
- Arc 8 represents U.S.-manufactured finished goods that are exported. Peacetime or steady-state exports are forecast by economic models. In the national emergency scenario, they are generally decremented from their peacetime levels so that items formerly exported can be available to satisfy domestic needs. The sum of arcs 7 and 8 represents the output of U.S. industry.
- Arc 9 represents U.S. imports of finished goods, or equivalently, foreign-produced goods that are exported to the U.S. This plays a key role in the shortfall computation process. Peacetime or steady-state imports are forecast by economic models. In the national emergency scenario, they are decremented from their peacetime levels to account for supplier country unreliability and other factors.

- Arc 10 represents foreign-manufactured finished goods that are not exported to the U.S. RAMF-SM does not explicitly model them.

Actually, RAMF-SM Step 2 is somewhat more disaggregated than Figure A2b.1 in that it often treats different foreign countries separately, instead of amalgamating them into a single "foreign" source. U.S. demand is also separated into defense, civilian, and emergency investment categories. For the purposes of this appendix, the more aggregated figure will suffice. The two-level distinction "raw material" vs. "finished goods" is admittedly aggregated.

Material Demands, MCRs, and Embedded Demand

The U.S. demands for goods and services indicated in the upper right-hand box of Figure A2b.1 (which is marked "Box D") are all considered essential (non-essential civilian demands are explicitly not included in the Base Case). They are treated as givens that must be met, either by U.S. production or by imports. If some imports of foreign goods are cut off because of the unreliability, et al., of supplier countries, then the corresponding demands must be met by U.S.-manufactured products. So the demands can be partitioned into demands met by imports and demands met by U.S. industrial production.

Although the MCRs are computed based on U.S. material consumption and economic data, let us assume that foreign production processes are sufficiently similar to U.S. ones so that the MCRs remain valid for foreign production. Thus a given dollar amount of output in a given industry requires the MCR times that dollar amount of raw material to produce it, whether or not that production occurs in the U.S. or abroad.

The material required to produce the goods and services demanded by the U.S. (i.e., Box D in Figure A2b.1) is computed by multiplying the MCRs by the demand amounts (material by material, industry sector by industry sector). This can be partitioned into material amounts needed by U.S. industry in its production processes to satisfy domestic demand (Arc 7 in the figure)—and the embedded material associated with imports. The embedded material is computed by multiplying the amount of imports (Arc 9 in the figure) by the MCRs.

U.S. industry also needs material to produce the goods destined for export. The overall amount of material needed by U.S. industry in its production processes is then determined as:

MCR × [Total industrial output needed to satisfy U.S. demand (Box D)

+ U.S. industrial output used to produce goods for exports (Arc 8)

- foreign industrial output that produced imported goods (Arc 9)]

(Algebraically, this is also equal to the MCR multiplied by the sum of Arc 7 and Arc 8.) This computation is performed separately for each combination of material of interest and industry sector.

Computation of Available Material Supply

After the material demands have been computed, the next stage is to compute the available material supply. The following procedure is performed separately for each material under consideration:

1. Start with projected steady-state material supply amounts (measured in mass units, such as tons), by country of origin (including the United States) and year of the Base Case. The amount might correspond to capacity, estimated production, or an estimate in between the two metrics. Most of the data on supply amounts are furnished by the USGS.

2. Separate U.S. material supplies into current facilities, restart concerted programs and new/expansion concerted programs, and determine the U.S. supply amounts available for each category. (Concerted programs are future sources of supply that require substantial start-up investment costs. They are assumed not to be available in the Base Case).

3. Determine each foreign country's supply use category, that is, whether its supply can be used to satisfy all categories of material demand (defense, emergency investment, and civilian) or civilian material demand only.

4. For foreign supplies, apply decrement and delay factors to determine the amounts of available foreign supply, by year and country of origin. These factors model the effects of the underlying conflict scenario on material supply and include factors for supply shutoff from adversaries, war damage, shipping losses, infrastructure/ability degradation, anti-U.S. orientation, and foreign competition (i.e., U.S. market share).

5. For each combination of use category and year, take the sum over country of the available foreign supply amounts to get a total available foreign supply for that use category and year. If useable foreign supply is to be capped at a multiple of current material imports, apply that cap.

Computation of Material Shortfalls

After the available material supply has been determined, it is compared with material demand and the resulting shortfalls, if any, are computed. There are three categories of demand: defense (encompassing steady-state military plus extraordinary military), emergency investment, and civilian. There are also three categories of supply:

1. Domestic (U.S.) supply.
2. Foreign supply that can be used to offset demand in all categories (net amounts available after all decrement factors have been applied).
3. Foreign supply that can be used to offset civilian demand only (net amounts available after all decrement factors have been applied).

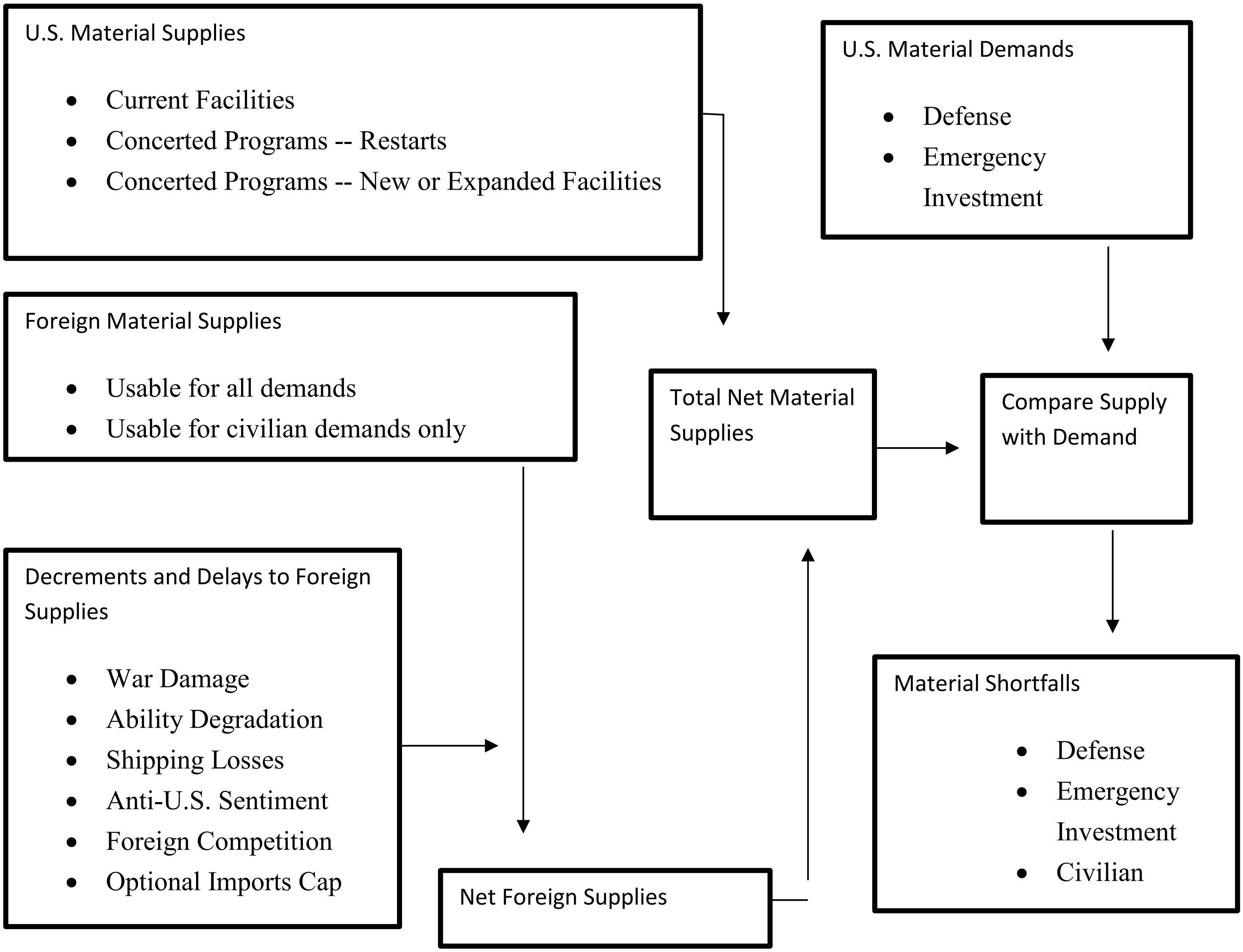
All supplies and demands are time-phased streams: separate supply and demand quantities are generated for each year of the Base Case. The comparison algorithm is performed separately for each different material. It tries to maximize the amount of demand satisfied (and hence minimize the shortfall), subject to the following constraints:

- Supply that becomes available in a certain year is not allowed to offset demand in earlier years;
- Foreign supply that can be used to offset civilian demand only cannot be used to satisfy defense and emergency investment demands;
- Attempt to satisfy defense demands first, then emergency investment, then civilian; and
- Use U.S. supply in preference to foreign, where feasible.

Shortfalls, if any, as well as the available U.S. and foreign supply, and also the amount of foreign supply used are noted.

Summary Flowchart

The flowchart in Figure A2b.2 illustrates the material supply modeling and demand/supply comparison process, putting together all of the elements described above.



Note: All quantities can vary by year.

Figure A2b.2. Material Supply Modeling Methodology

Appendix 2c. Data and Sources for Modeling Gross Shortfalls

After selecting the list of materials for study in the 2015 National Defense Stockpile (NDS Program) report, the Defense Logistics Agency Strategic Materials gathered the data necessary to support the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) material shortfall assessment.

Overview

The data items, and their associated sources, discussed in this appendix pertain to Step 2 of RAMF-SM for upstream material shortfall assessments. The data categories used in the RAMF-SM process to arrive at gross shortfall values include the following:

- Economic data including projected demands for goods and services and prices
- Material consumption data
- Material supply data
- Military conflict scenario, platform loss, and munitions expenditure data
- Intelligence community assessments of country reliabilities and capabilities

Economic Data

The objective of RAMF-SM Sub-step 2A is computing projected demands for goods and services under Base Case conditions. These data are generated by translating the long-range economic forecast prepared by the Council of Economic Advisors (CEA) into output requirements for each industrial sector. This is computed using two economic models developed by the Inter-industry Forecasting Project (INFORUM) at the University of Maryland. The inputs to the economic models are calibrated to match the CEA macroeconomic forecast.[15]

Austerity measures known as “reduction factors” are applied to civilian demand to determine essential civilian requirements during the Base Case.

Economic data for emergency investment is obtained from the U.S. Census Bureau. The U.S. Census Bureau provides data on U.S. plant capacity utilization and emergency capacity utilization, also categorized by NAICS code. The data is compiled from surveys of U.S. manufacturing establishments.

[15] The data used for the Base Case economic inputs are consistent with the CEA’s 2013 Mid-Summer review data, released in July 2013. The federal government budget data in the forecast were updated in March 2014 to reflect the President’s Budget for Fiscal Year 2015.

Material price data is used to estimate the value of material shortfalls. Historical prices are used and generally obtained from commercial market reporting sources.

Material Consumption Data

Material consumption data is used to determine material demands required to fulfill the demand for goods and services (Material Consumption Ratios, MCRs). The NDS Program contracts with the U.S. Department of Commerce and the United States Geological Survey (USGS) to obtain historical material consumption data by main application which are then projected into the Base Case scenario period using the economic data. The Commerce and USGS data cover most of the materials under study. For many of the specialized materials, the NDS Program uses Federally Funded Research and Development Center and industry subject matter experts (SMEs) to obtain the consumption data. These data are generally provided for use at the proprietary level and are subject to protection from disclosure.

Material Supply Data

For most materials under study, data on supply are obtained from the USGS. These data include historical estimates of production by country, and projections of U.S. and foreign supply capacity over the scenario period. For specialized materials, the NDS Program uses Federally Funded Research and Development Centers and industry subject matter experts (SMEs) to obtain supply data. The supply data for these materials are also considered proprietary and are subject to protection from disclosure.

Military Conflict Scenario, Platform Loss, and Munitions Expenditure Data

OSD Policy approves the use of a specific (classified) combat planning scenario which is used in RAMF-SM. Both platform loss and munitions expenditure data are obtained from the Office of the Secretary of Defense Joint Data Support (OSD JDS) which maintains archives of these studies.

Intelligence Community (IC) Assessments of Country Reliabilities and Capabilities

Members of the Intelligence Community (IC) provide the NDS Program with a classified assessment of country reliabilities and capabilities which is used in RAMF-SM to ascertain reliable material supplies during the Base Case. These data were elicited via a formal tasking letter that was coordinated by the Institute for Defense Analyses (IDA) on behalf of the NDS Program.

List of 71 Major Data Items Required

The broad areas of data inputs discussed in Chapter 5.1 provide only the highlights of the data requirements for Step 2 of RAMF-SM. The total number of individual data values is in the thousands. But these can be organized into 71 major data items (including databases and control inputs[16]). These items, along with the source of the data and the data type, are listed in Table A2c.1.

Table A2c.1. List of Databases, Data Items, and Control Inputs for RAMF-SM Step 2 (Material Shortfall Assessment)

No.	Data Type	Data Element	Source/Information Provider
1	Conflict scenario data	Approved use of scenarios and scenario products including: location, countries involved	OSD-P, DUSD for Strategy, Plans and Forces
2	Conflict scenario data	Homeland damage component	OSD-P, DUSD for Strategy, Plans and Forces
3	Conflict scenario data	Overall dates and timeline	OSD-P, DUSD for Strategy, Plans and Forces
4	Conflict scenario data	War damage factors	OSD/Joint Staff, Services
5	Conflict scenario data	Shipping loss factors	OSD/Joint Staff, Services
6	Conflict scenario data	Alternative futures, and above requirements for each	OSD-P, DUSD for Strategy, Plans and Forces
7	Weapon-related data	Weapons lost and expended in the conflict scenario	OSD/Joint Staff, Services
8	Weapon-related data	Weapon costs, including appropriate inflation factors	IDA
9	Weapon-related data	Major End Item names, mapping, and types	OSD/CAPE
10	Weapon-related data	Defense translator vectors or decision on amounts for economic modeling	OSD/CAPE
11	Weapon-related data	Weapon production lead times	OSD, IDA
12	Weapon-related data	Control inputs concerning production times	NDS Program

[16] In this context, the term control inputs refers to single data elements such as option indicators and adjustment percentages that are not parts of a larger database or data set.

Table A2c.1. List of Databases, Data Items, and Control Inputs for RAMF-SM Step 2 (Material Shortfall Assessment) (continued)

No.	Data Type	Data Element	Source/Information Provider
13	Weapon-related data	Above data for alternative futures	OSD/Joint Staff, Services
14	Economic Data Package	Economic Forecast	CEA, INFORUM, IDA
15	Economic Data Package	List of economic sectors and their names	INFORUM
16	Economic Data Package	Dollar year for data	INFORUM
17	Economic Data Package	Input-output matrices	INFORUM
18	Economic Data Package	Forecast economic files—peacetime (civilian, defense, exports, imports, output)	IDA
19	Economic Data Package	Forecast economic files—civilian austerity with advice of Civilian Agency Working Group (CAWG)	IDA
20	Economic Data Package	Forecast economic files—homeland damage	IDA
21	Economic Data Package	Data set on austerity profile (what levels, in which years)	NDS Program, Civilian Agencies
22	Economic Data for Emergency Investment	Capital coefficients	INFORUM
23	Economic Data for Emergency Investment	Capital/output ratios	INFORUM
24	Economic Data for Emergency Investment	Investment lead times	IDA
25	Economic Data for Emergency Investment	Survey of Plant Capacity data for industry expansion	Census
26	Economic Data for Emergency Investment	Control inputs--several	NDS Program
27	Export Factor Adjustments	Control input	NDS Program
28	Import Factor Adjustments	Matrix of imports by industry and country	DoC, USATradeOnline

Table A2c.1. List of Databases, Data Items, and Control Inputs for RAMF-SM Step 2 (Material Shortfall Assessment) (continued)

No.	Data Type	Data Element	Source/Information Provider
29	Import Factor Adjustments	Reliability, enemy zero-out, anti-U.S. sentiment, war damage, and shipping loss data (must be consistent with conflict scenario, same as used for material supply adjustment in Stockpile Sizing Module, prerequisite for import factor adjustments).	IC, OSD/Joint Staff, Services, others
30	Import Factor Adjustments	Control inputs on modeling of anti-U.S. sentiment	NDS Program
31	MCR Creation Process	Material consumption for recent year or year span	DoC, USGS, industry
32	MCR Creation Process	Application areas and percentage breakdown of use by application	DoC, USGS, industry
33	MCR Creation Process	Association of application areas with industry (ILIAD) sectors	IDA
34	MCR Creation Process	Units of measure	DoC
35	MCR Creation Process	Historical economic data for recent year or year span	INFORUM
36	Computation of Material Demands	Material consumption ratios	Various (see items 31-35)
37	Computation of Material Demands	FORCEMOB output data (FORCEMOB run is a necessary prerequisite to material demand calculation)	IDA
38	Computation of Material Demands	Units of measure	NDS Program
39	Computation of Material Demands	Alternative computational methodology for materials for which MCR method is inappropriate	IDA
40	Computation of Material Demands	Special treatment of certain materials as needed (e.g., green ammo addition of tungsten in 2005 study)	NDS Program

Table A2c.1. List of Databases, Data Items, and Control Inputs for RAMF-SM Step 2 (Material Shortfall Assessment) (continued)

No.	Data Type	Data Element	Source/Information Provider
41	Computation of Material Demands	Aluminum supply for metal-grade bauxite demand calculation (aluminum redistribution function). Not necessary if metal-grade bauxite is not modeled.	USGS
42	Basic Material Supply Information	List #1 of materials to model. For each material, data elements listed in items 43-55 will be needed.	NDS Program
43	Basic Material Supply Information	U.S. production for recent year or years	USGS, IDA, NDS Program, others as appropriate
44	Basic Material Supply Information	Foreign production, by country, for recent year or years	USGS, IDA, NDS Program, others as appropriate
45	Basic Material Supply Information	U.S. capacity, estimated year by year starting with recent year and for each year of the scenario	USGS, IDA, NDS Program, others as appropriate
46	Basic Material Supply Information	Foreign capacity, estimated year by year starting with recent year and for each year of the scenario	USGS, IDA, NDS Program, others as appropriate
47	Basic Material Supply Information	Separation by assuredness level of production facility	USGS, IDA, NDS Program, others as appropriate
48	Basic Material Supply Information	Listing of specific production facilities, if available	USGS, IDA, NDS Program, others as appropriate
49	Basic Material Supply Information	Concerted programs	USGS, IDA, NDS Program, others as appropriate
50	Basic Material Supply Information	Refinery capacity, if appropriate and available	USGS, IDA, NDS Program, others as appropriate
51	Basic Material Supply Information	Imports	USGS, IDA, NDS Program, others as appropriate
52	Basic Material Supply Information	Exports, if used in new modeling	USGS, IDA, NDS Program, others as appropriate

Table A2c.1. List of Databases, Data Items, and Control Inputs for RAMF-SM Step 2 (Material Shortfall Assessment) (continued)

No.	Data Type	Data Element	Source/Information Provider
53	Basic Material Supply Information	Ramp-up times	USGS, IDA, NDS Program, others as appropriate
54	Basic Material Supply Information	Prices. Be sure to convert units of measure for prices appropriately.	USGS, IDA, NDS Program, others as appropriate
55	Basic Material Supply Information	Current and projected NDS Program inventories and legal stockpile goals	NDS Program
56	Foreign Supply Decrement Factors	Ability/infrastructure factors	IC
57	Foreign Supply Decrement Factors	Anti-U.S. sentiment factors	IC
58	Foreign Supply Decrement Factors	War damage factors	OSD/Joint Staff, Services
59	Foreign Supply Decrement Factors	Shipping loss factors	OSD/Joint Staff, Services
60	Foreign Supply Decrement Factors	Delay time for material delayed due to anti-U.S. sentiment (control input)	NDS Program
60a	Foreign Supply Decrement Factors	Control factor: length of time supply from enemy countries is set to zero	NDS Program
61	Information for Market Share Determination	Lists of demander countries	USGS, industry
62	Information for Market Share Determination	GDP data, growth rate estimates, and inflation factors	CIA World Factbook, other sources
63	Information for Market Share Determination	War damage decrement factors	OSD-P, Military Services
64	Information for Market Share Determination	Countries not in U.S. trading bloc	State Department
65	Information for Market Share Determination	U.S. imports. Provided as part of basic supply data.	USGS, others as needed

Table A2c.1. List of Databases, Data Items, and Control Inputs for RAMF-SM Step 2 (Material Shortfall Assessment) (continued)

No.	Data Type	Data Element	Source/Information Provider
66	Information for Market Share Determination	Non-U.S. production. Provided as part of basic supply data.	USGS, others
67	Information for Market Share Determination	Decision on methodology	NDS Program
68	Information for Market Share Determination	Expanded market share decision (control input)	NDS Program
69	Usability Code Rules (control inputs)	Dominator criterion	NDS Program
70	Usability Code Rules (control inputs)	Countries the supply from which is always defense-usable	NDS Program
71	Usability Code Rules (control inputs)	Completely unreliable countries	NDS Program

NDS Program analysts closely review the data inputs above, and engage in a detailed decision-making process regarding each input. The NDS Program judgment and approval process is discussed next.

Appendix 2d. Assumptions, Key Judgments, and Approval Process

Once materials for the 2015 National Defense Stockpile (NDS Program) study were selected and data needs were identified, the Department reviewed the overall Base Case scenario description and determined the supply-side and demand-side assumptions. This appendix presents these assumptions, followed by the list of key judgments made by the Department (i.e., NDS Program and other DoD offices). These judgments dictated how each data input into the Risk Assessment Mitigation Framework for Strategic Materials (RAMF-SM) was treated in the modeling and analyses required for this 2015 NDS Program report.

Overall Scenario Description

Sections 14(b) and 14(c) of the Strategic and Critical Materials Stock Piling Act require that the Secretary of Defense "shall base the national emergency planning assumptions on a military conflict scenario consistent with the scenarios use by the Secretary in budgeting and defense planning purposes."[17] In addition, some of the assumptions for the analysis include: (1) a four-year national emergency scenario that assumes one year of conflict followed by three years of recovery/regeneration (e.g., repair of homeland damage, building the replacement requirements for the weapon losses and munition expenditures, continuing foundational activities), (2) estimates of all relevant defense sector demands (including those necessary to regenerate weapon systems lost and munitions expended in the conflict), and (3) essential civilian sector demands. For the purpose of this analysis, the national emergency scenario is postulated to cover four complete years: the beginning of 2017 through the end of 2020.

The 2015 NDS Program military conflict scenario draws from elements of the Integrated Security Constructs (ISCs) for which the United States must be prepared (based on the classified, priority Defense Planning Scenarios promulgated by the Secretary of Defense for DoD programming and budgeting purposes).

The conflict, which occurs within the first year of the four-year national emergency scenario, was constructed as a hybrid to include the following: (1) a catastrophic attack on a U.S. city by a foreign terrorist organization or rogue state; (2) two, near-simultaneous major combat operations (i.e., state vs. state conflicts); (3) war damage from a near-peer competitor, and (4) ongoing foundational activities (i.e., deterrence, forward presence, and building partner capacity). Replacement requirements for weapon losses and munitions expenditures in the major combat operations were developed by the Office of the Secretary of Defense/Cost Analysis and Program Evaluation (OSD/CAPE).

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[17] See Appendix 1 of this report for additional details.

The combination of these four areas addresses the statutory requirements for the NDS Program Report to Congress while also conforming to OSD Policy guidance.[18]

Supply-Side Assumptions for the Base Case

U.S. Production, Capacity, and Ramp-up

U.S. material producers operating at less than full capacity could increase output to mobilization levels (i.e., full production within existing capacity) during a contingency. The United States is assumed to be able to obtain all of the current output and any increased output. The Base Case assumes that during the first six months of the first scenario year, the United States may acquire the estimated production from U.S. producers. After the first six months of the scenario, the United States is assumed to be able to acquire the full-capacity output of U.S. producers. This is consistent with an assumption that moving to mobilization levels will also take approximately six months to obtain all necessary additional skilled labor, production equipment, permits and funding. The national emergency posited in the Base Case postulates that all necessary funding will be made available by the U.S. Government to achieve these levels of production.

Note that the U.S. supply does not include any inventory that might be in the NDS Program . The idea is to determine whether available material supply—under the Base Case assumptions, without any mitigation measures applied—is sufficient to offset material demand. If it is not, various mitigation measures, including stockpiling, are considered.

Foreign Production, Capacity, and Ramp-up

Foreign material producers operating at less than full capacity could increase output to mobilization levels (full production within existing capacity) during a contingency. Depending on the extent of global shortages and competition for supplies, the United States is assumed to be able to obtain its normal market share of any increased output (subject to adjustments for reliability, war damage, and shipping losses, as mentioned below). The Base Case assumes that during the first six months of the first scenario year, the United States may acquire its normal market share of estimated reliable, undamaged foreign production from countries that are not enemy combatants. After the first six months of the scenario, the United States is assumed to be able to acquire its normal share of full-capacity output. As with U.S. supply, this is consistent with an assumption that moving to full capacity mobilization levels will take, on average, about six months to

[18] OSD Policy would like to highlight that these scenarios: (a) are estimates of future demands, (b) reflect the current strategy (i.e., it's not a post-sequestration strategy), and (c) are not force-managed in conjunction with other contingencies. These products are in the early stages of being revised and there may be potential changes to forces and Concept of Operations (CONOPS).

obtain all necessary additional skilled labor, production equipment, permits and funding. The national emergency posited in the Base Case postulates that all necessary funding will be made available by the U.S. Government to achieve these levels of production.

Secondary Supply

Secondary U.S. supply (i.e., recycled material) is assumed to be available in the amounts indicated in the databases, and is assumed to be capable of offsetting defense (and emergency investment) demands, as well as civilian demands. It is believed that in a national emergency reprocessing capability, rather than the availability of scrap feedstock, will be the tightest factor in determining the amount of usable secondary supply. The USGS secondary supply data are for reprocessing capacity.

Unlike past reports, for the 2015 report there was an effort to identify foreign sources of secondary supply and include them in the foreign supply amounts. Like all foreign supplies, the RAMF-SM modeling adjusts them by a market share factor and conflict-related decrement and delay factors.

Concerted Programs

Concerted programs represent potential material production facilities that are not currently in operation, but could be brought online after a period of time if a certain (possibly large) amount of money were invested in them. Such programs might include restarts of dormant facilities, expansions at existing facilities, or construction of new facilities. However, the 2015 Base Case assumes that concerted programs will not be available. Rather, it only assumes the availability of production capability that is already active or that is currently expected to become active during the Base Case time frame, whether U.S. or foreign. Without significant pre-planning and contingency contract arrangements, the timelines for activating concerted programs are assumed to be too long to be relevant for Base Case assessments.

Supply from Combat Adversaries (enemy combatants)

Enemy combatant states are not considered available to supply materials, goods, and services to the United States for a period of time surrounding the conflict, due to some combination of enemy embargoes, U.S. sanctions, and potential war damage. The Base Case assumes this “no-supply” period lasts for one year. During that year, the enemy combatant states’ supplies are unavailable to the United States. The availability of such supplies in subsequent years is assumed to be a function of the particular country’s infrastructure reliability, lingering anti-U.S. sentiment, and other relevant scenario considerations mentioned in this section.

Supply from Unwilling Countries (anti-U.S. sentiment)[19]

Some foreign governments, not necessarily directly involved in combat, may be judged partially or completely unwilling to supply materials to the United States as a result of the contingency. Under Base Case assumptions, the United States is assumed to eventually obtain its normal share of the "unwilling fraction" of those materials, even from unwilling sources, by dealing with third parties on global markets. However, such indirect acquisitions will be subject to non-trivial delays. For the Base Case, the delay for materials is assumed to be six months. The proportion of a country's materials deemed unreliable due to unwillingness (and thus subject to a six-month delay) depends on the degree of its hostility, as indicated by a willingness score provided by the Intelligence Community (IC) (see Appendix 2f).

Foreign Infrastructure/Ability Reliability Factors

Some foreign economies, not necessarily directly involved in combat in the Base Case, may be judged more or less able to supply the quantity of materials that they might normally provide based on their current production levels and supply capacities. Thus, they may prove unreliable as a result of scenario-specific levels of political instability, labor unrest, or breakdowns in transportation or power infrastructures. (Note that foreign infrastructure reliability is a separate source of decrement than war damage itself.) Such scenario-specific problems are estimated by the IC. The evaluators assign a value (0 to 100 percent) of a country's anticipated material output that is assumed to be lost due to this factor. See Appendix 2f for more details.

War Damage Factors

Countries involved in the conflict are subject to war damage that might affect their ability to produce materials, goods, and services. Reduction factors to model war damage are set to be consistent with the particulars of the conflict scenario. See classified Appendix 2g for details.

Shipping Loss Factors

Material and goods from certain countries might be subject to losses in transit due to attack from enemy countries. Reduction factors to model this depend on the country of origin, and are set to be consistent with the particulars of the conflict scenario. See classified Appendix 2g for details.

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[19] Any material subject to a delay from an unwilling country is assumed to be unavailable to satisfy any U.S. defense demands. The delayed material, however, can be used to satisfy U.S. civilian demands.

U.S. Share of Foreign Supplies ("U.S. market share")

Another input to the requirements estimation process is the share of foreign material supplies that the United States can expect to acquire. Other countries, especially our allies and friends, will need a portion of available materials to meet their needs and unfriendly countries may still be able to outbid the United States on world markets for materials. Accordingly, the Base Case limits the U.S. share of the scenario-specific estimates of reliable foreign production to the largest of three measures: (1) the share of foreign projected peacetime production that when added to projected U.S. peacetime production will exactly equal U.S. projected peacetime demand, where the projections are for the first scenario year (2017); (2) the current U.S. share of foreign production; and (3) its share of the combined gross domestic products (GDPs) of the countries that demand the material.

The rationale for the third measure is as follows. GDP is considered a measure of ability to bid for material. Other things being equal, the larger the U.S. GDP is relative to the GDPs of other countries that demand the material, the more material for which the United States can successfully acquire. In a national emergency, if necessary, the U.S. is assumed to be able to use its economic power to bid for a larger share of material than it imports in peacetime, but this share is limited by the GDP ratio.

A separate market share value is computed for each material. For most materials, the third measure, the GDP ratio, is the largest. This regular share operates in addition to the conflict-related decrement factors. In the Base Case, only the regular share of foreign supplies, as indicated above, is allowed. A possible market response involves the United States purchasing an extra share of foreign production that corresponds to currently unused capacity. See Appendix 3c for details on the market response, "Extra Sell".

Usability of Supply to Satisfy Defense Demand (foreign market dominators)

The modeling process allows certain foreign material supply to be precluded from satisfying U.S. defense and emergency investment demands. (It can, however, be used to satisfy essential civilian demand.) A number of input factors govern exactly which kinds of foreign supply are assumed to be capable of offsetting defense demand.

In the 2015 Base Case, available foreign supply (after all the relevant decrements mentioned above have been applied) is allowed to offset defense demand—unless the material comes from a country that is a "market dominator," defined as a foreign country that produces more than half of the global production of that material.[20] As in past NDS Program Requirements Reports, the 2015 Base Case assumption is that a market

[20] This calculation/assessment of a market dominator is made prior to applying any decrements to the initial supply estimates.

dominator's production may not be counted upon by the United States to meet defense (and emergency investment) demands. The reason for this is the belief that it is especially risky to depend upon supplies from a single foreign source rather than from a variety of such sources, given the greater potential for accidents, natural disasters, or deliberate sabotage, not otherwise explicitly accounted for in the scenario, to disrupt a single source by comparison with multiple sources. Such dependence on a single source is assumed in the 2015 Base Case to be unacceptably risky in regard to meeting defense demands. An alternative plausible assumption could extend this restriction to essential civilian demands as well.

Single Point of Failure

In order to properly categorize all risks associated with strategic material supply chains, Section 2(b) of the Strategic and Critical Materials Stock Piling Act (50 U.S.C. 98a(b)) was amended in the National Defense Authorization Act for Fiscal Year 2013 (Public Law 112-239). The phrase "or single point of failure" was added after "foreign sources": "...to decrease and to preclude, when possible, a dangerous and costly dependence by the United States upon foreign sources or a single point of failure for supplies of such materials in times of national emergency."

A single point of failure is a facility or site that is the sole domestic location where a material is mined, processed or produced and for which dependence upon it for supply in a national emergency could prove to be dangerous and costly. Foreign production of the material is addressed separately, under the "foreign market dominator" criterion. Supply from single points of failure was not used to meet national emergency demand for the 2015 NDS Program Requirements Report Base Case.

Demand-Side Assumptions for the Base Case

The 2015 Requirements Report Base Case demands for essential goods and services are projected on a time-phased basis for all military, industrial, and essential civilian uses of strategic and critical materials under the specified four-year Base Case. For the 2015 NDS Program Requirements Report Base Case, this requires projections for the conflict year (2017) and each of the three regeneration years (2018–20). Some of the specifics are discussed below.

Economic Growth

The study projects future U.S. demands for strategic and critical materials based, in part, on an official recent forecast of the U.S. economy. The data used for the Base Case economic inputs are consistent with the President's Council of Economic Advisors' (CEA's) 2013 Mid-Summer review data, released in July 2013. The federal government budget data in the forecast was updated in March 2014 to reflect the President's Budget for fiscal year 2015. This official forecast is used by the Administration to support policy and budgetary deliberations.

Defense Demand

Goods and services consumed by the defense sector consists of two parts. The first part corresponds to consumption under the ongoing defense budget. Demands upon each of 360 sectors of the U.S. economy are estimated using special economic forecasting models from the Inter-industry Forecasting Project at the University of Maryland (INFORUM). The inputs to these models are set to be consistent with the Future Years Defense Program (FYDP) for fiscal years 2017 through 2020. The second part corresponds to goods and services needed to rebuild key weapons lost and consumed in the postulated Base Case conflict scenario. These demands are estimated using data from the Assistant Secretary of Defense for Cost Assessment and Program Evaluation, as well as information from INFORUM. All defense demands are considered essential.

Essential Civilian Demand

Goods and services consumed by the civilian sector are projected over the scenario period (i.e., 2017 through 2020) using the economic forecasting models from the INFORUM organization. The inputs to these models are set to be consistent with the CEA's forecast of the economy for that period, as mentioned above.

Consistent with past reports, this report assumes many of these civilian demands for goods and services will need to be met. However, under Base Case assumptions, not all goods and services consumed in the civilian sector are deemed essential. Thus, reductions are made for some civilian demand to preclude stockpiling for items that would be considered nonessential during the one-year conflict and three-year regeneration period. These reductions in civilian demands are consistent with the Stock Piling Act requirement that only essential civilian needs should be taken into account when determining how much material should be stockpiled. In this regard, this report does not assume that the Federal Government would necessarily impose wide and detailed regulations to ration nonessential goods and services during the four-year Base Case. The market economy might provide these goods and services at the level estimated in the peacetime forecast. However, consistent with the statutory guidance, the NDS Program will not be structured to ensure the availability of nonessential items by stockpiling materials for their production.

The study uses certain factors to determine the portion of forecasted civilian demand that should be considered essential and thus be included in the essential demands under the Base Case. The factors are less stringent in the first (combat/conflict) year than in the subsequent three years of regeneration. Appendix 2e provides more details on these reduction factors.

Imports and Exports

The economic forecasting models from the University of Maryland, which forecast defense demand and civilian demand for goods and services, also forecast imports and exports of goods and services (for each of 360 different sectors of the economy), under peacetime (baseline, steady-state) conditions. Goods produced for export constitute a source of material demand (the materials needed to produce these goods). Conversely, materials contained in imports of finished goods lessen the demand for the materials needed to produce such goods domestically. When computing the material demand that the U.S. Government needs to address via stockpiling or other measures, the modeling process considers some portion of the material amounts associated with imports and exports.

The material amounts associated with imports and exports can be adjusted to be concordant with the national emergency scenario. This is modeled by decrementing the forecasted imports and exports of goods and services, and then using these decremented values when computing material demand from industrial demand. The decrement factors vary by sector of the economy. Imports are decremented in the Base Case to factor in the "unreliabilities" from the particular countries of origin (provided by members of the IC). Imports of goods from adversary countries are considered unavailable during the one-year conflict scenario. Exports are judgmentally decremented to reflect the fact that in a national emergency, (a) the United States might need some of the goods that would otherwise be exported, (b) the United States might need the material used to produce those goods, or (c) the United States might not want to guarantee government coverage for one or more of those materials. In the Base Case, for most sectors of the economy, exports of goods and services are set to 85 percent of their forecasted peacetime values, in all years of the scenario.

Homeland Recovery

A catastrophic attack on a major U.S. city by a foreign terrorist organization or rogue state would cause substantial destruction of fixed assets and consumer durables. The Base Case assumes that such an attack occurs in the first year. A homeland recovery program to replace those lost fixed assets and consumer durables would require a total of approximately $200 billion in private and government spending over the following three regeneration years. These recovery demands are treated as essential. They are apportioned between the defense, essential civilian, and import demand sectors for estimation and tracking purposes in this 2015 NDS Program study.

Key Judgments and Approval Process

As part of a comprehensive data validation effort underway at the National Defense Stockpile (NDS Program), all key judgments associated with each step of RAMF-SM were considered by the NDS Program management (or, in some cases, other DoD organizational authority), and, where applicable, material level details were assigned to one of four material leads within the organization. Each material lead reviewed all material-level data inputs, decisions, and outputs associated with the RAMF-SM analyses. Table A2d.1 offers examples of such judgments made in support of RAMF-SM Step 2.

Table A2d.1. Key Judgments in Support of RAMF-SM Step 2

Data Type	Description of Judgment/Policy Variable	Approach for 2015 Report	Decision Maker
Conflict scenario data	War damage factors	Specific classified set	OSD-Policy
Conflict scenario data	Shipping loss factors	Specific classified set	OSD-Policy
Weapon-related data	Platform losses and munitions expenditures for the conflict scenario	Sum of maximum values for CC1 and CC3	OSD-Policy
Weapon-related data	In calculating industry demand, FORCEMOB uses production times for Major End Items. Emergency production times may be set equal to peacetime production times, or may reflect compressed (or lengthened) production times as a percentage factor.	Emergency lead times set at 90 percent of peacetime lead times	NDS Program
Weapon-related data	Rather than using what is in the input file, impose a minimum emergency production time in terms of a number of months.	1 month	NDS Program
Weapon-related data	Rather than using what is in the input file, impose a maximum emergency production time in terms of a number of months.	None imposed	NDS Program
Weapon-related data	For long production time items (production times longer than the scenario period), determine what proportion to produce.	Production proportionate to scenario period	NDS Program
Economic data package	Adjustment factor for civilian demand	No adjustment	NDS Program

Table A2d.1. Key Judgments in Support of RAMF-SM Step 2 (continued)

Data Type	Description of Judgment/Policy Variable	Approach for 2015 Report	Decision Maker
Economic data package	Adjustment factor for base military demand	No adjustment	NDS Program
Economic data package	Homeland damage	$200B in spending over three regeneration years	NDS Program
Economic data package	Essential civilian requirements to support the national emergency, and civilian austerity measures required during the Base Case.	Revised based on Civilian Agency input	NDS Program with input of Civilian Agencies
Economic data for emergency investment	Percentage value, for all industries, that a plant will expand from current operating capacity towards Emergency Operating Capacity (EOC).	90 percent	NDS Program
Economic data for emergency investment	Military/civilian fungibility, or dual use, factors are used to model the interchangeability of military versus civilian productive capacity. If no percentage is selected, all industries are assumed to have complete fungibility. A selected percentage indicates the percentage of productive capacity that is interchangeable.	Set to 50 percent fungibility for all industries	NDS Program
Economic data for emergency investment	Ramp up time is the amount of time, in months, that it takes for a plant to expand from its current operating level to the new level.	6 months	NDS Program
Economic data for emergency investment	Investment lead times gives, for each industry, the amount of time (in months) necessary to build additional productive capacity in that industry. A percentage factor, or multiplier, may be used to adjust lead time values. The same factor is used for all industries. A factor of less than 100 percent reduces lead times in concordance with a mobilization scenario. A factor greater than 100 percent can be used to examine the effect of lengthening the lead times.	90 percent	NDS Program

Table A2d.1. Key Judgments in Support of RAMF-SM Step 2 (continued)

Data Type	Description of Judgment/Policy Variable	Approach for 2015 Report	Decision Maker
Economic data for emergency investment	Additional capacity delay time is a variable that may be set to indicate a selected number of months after the simulation start that shortfalls are redressable via investment.	0	NDS Program
Economic data for emergency investment	Values to use for missing data in peacetime production fraction of Emergency Operating Capacity (EOC) by industry sector	Use average of industry sectors that have estimates	NDS Program
Export adjustment factors	Export adjustment factors, by industry and year, for a specified range of years (not necessarily the whole scenario period).	Use the same factors as used in the 2013 NDS Program Report (85 percent for most industries for all years)	NDS Program
Import adjustment factors	List of designated enemy countries	Use set of countries designated in Future 1	OSD-Policy
Import adjustment factors	Period of complete supply shutoff for designated enemy countries	1 year	OSD-Policy
Import adjustment factors	Decrement U.S. goods and services (G&S) imports due to foreign inability to produce/delay due to unwillingness to sell to US	Use IC ability and unwillingness factors as proxy; apply time delay of six months for goods and services due to unwillingness	NDS Program
MCR Creation Process	Consumption information and application areas	Information from USGS, Commerce, and/or material lead	NDS Program

Table A2d.1. Key Judgments in Support of RAMF-SM Step 2 (continued)

Data Type	Description of Judgment/Policy Variable	Approach for 2015 Report	Decision Maker
MCR Creation Process	Years of historical consumption information to use	Recent years (2010-2012 where available, will differ by material and availability of data)	NDS Program
MCR Creation Process	Association of application areas with industry (ILIAD) sectors	Differs by material, mapped by IDA	NDS Program
MCR Creation Process	Units of measure	Units designated by NDS Program, synchronized with stockpile units	NDS Program
Basic Material Supply Information	Use of secondary production	Specific set (most recent update), differs by material	NDS Program
Basic Material Supply Information	Adjustment of peacetime supply estimates from USGS (estimates tend to flatline in outyears)	Supply adjustments, differs by material	NDS Program
US and Foreign Supply Estimates	Development of a method for handling missing data values; categorization of missing data performed and approach standardized within a category, where possible	Where possible, used a common approach to missing data	NDS Program

Table A2d.1. Key Judgments in Support of RAMF-SM Step 2 (continued)

Data Type	Description of Judgment/Policy Variable	Approach for 2015 Report	Decision Maker
Basic Material Supply Information	Use of capacity confidence levels	Specific set, differs by material, but unless otherwise specified by material lead, include Capacity Status 1 and 2 and exclude Capacity Status 3	NDS Program
Basic Material Supply Information	Ramp-up time for supply	Use 2013 approach	NDS Program
Basic Material Supply Information	Current and projected NDS Program inventories and legal stockpile goals	No legal goals for 2015 RR	NDS Program
Information for Market Share Determination	War damage GDP decrement factors	Same specific classified set as in 2013	NDS Program
Information for Market Share Determination	Decision on GDP methodology	GDPs projected to Base Case period using growth rates	NDS Program
Information for Market Share Determination	Decision on market share methodology	Used the larger value: initial clearing market share, imports to non-US production, or GDP ratio	NDS Program
Information for Market Share Determination	Expanded market share decision (control input)	Use 2013 approach	NDS Program

Table A2d.1. Key Judgments in Support of RAMF-SM Step 2 (continued)

Data Type	Description of Judgment/Policy Variable	Approach for 2015 Report	Decision Maker
Usability Code Rules (control inputs)	Dominator criterion	Use 2013 approach	NDS Program
Usability Code Rules (control inputs)	Single point of failure criterion	Not included in Base Case	NDS Program
Usability Code Rules (control inputs)	Countries where supply is always defense-usable	U.S. and Canada	NDS Program
Usability Code Rules (control inputs)	Completely unreliable countries	Specific set (most recent update)	NDS Program

Appendix 2e. Essential Civilian Demand Factors

The statute governing the National Defense Stockpile (NDS Program) requires that the Biennial Report on Stockpile Requirements set forth the National Security Planning Assumptions used by the Secretary of Defense in determining recommendations for stockpile requirements.[21] Two of the planning assumptions specified in the statute address civilian requirements, namely:

- The military, industrial, and *essential civilian* requirements to support the national emergency
- *Civilian austerity* measures required during the mobilization period and military conflict

This appendix describes the process established by the Department of Defense (DoD), after consultation with a civilian agency working group, to determine which civilian requirements should be considered essential.[22] The process uses percentage reduction factors to identify the portions of projected normal civilian demands deemed nonessential.[23] Essential civilian requirements are calculated by reducing projected demands by the percentages specified in the reduction factors. Only the decremented demands are considered essential and used in the determination of requirements for the materials included in this study.

The reduction factors serve to support key national security objectives while limiting potentially costly requirements for the materials included in this study. Requirements that are deemed essential can be grouped according to the following purposes:

- Procuring goods and services for defense;
- Sustaining supporting industries;
- Maintaining national economic strength;
- Providing government services;
- Maintaining an adequate civilian standard of living; and
- Recovering from an attack on the U.S. homeland.

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[21] See U.S. Code 50, § 98h-5.

[22] Civil departments and agencies invited to participate in the essential civilian demand decision process included Agriculture, Commerce, Energy, Health and Human Services, Homeland Security, Housing and Urban Development, Interior, Labor, the Office of Management and Budget, State, Transportation, and Treasury.

[23] Events during the crisis would influence civilian demands, both positively and negatively, across the four-year Base Case. However, essential civilian demands are calculated based on forecasts of normal peacetime demands.

Reduction factors are defined for 83 types of personal consumption and 25 types of construction, as shown in Tables A2e.1 and A2e.2 on the following pages.[24] As indicated in the tables, the factors are generally lower during year one of the four-year Base Case. This allows for a period of transition to help the civilian sector adjust to developing material shortages.

Personal Consumption Expenditures

The 83 spending categories listed in Table A2e.1 represent types of personal consumption. The values (including zeroes) in the table represent the percentage decrements imposed on projected civilian spending to eliminate non-essential items. For personal consumption, those categories with a "+"'sign are incremented proportionally so that total consumption across all the categories remains at the projected total level.

Generally, large reduction factors are specified for the various types of consumer durable goods, up to 75 percent for new automobiles, leisure vehicles, and jewelry. Consumer durables—those that are "consumed" over a longer period of time (e.g., vehicles and refrigerators)—are targeted because their production is especially intensive in the use of the materials included in this study.[25] In light of potential energy shortages, gasoline and foreign travel are also targeted for reductions.

For a number of personal consumption categories, a "+" sign is displayed in lieu of a reduction factor. These sectors generally represent nondurable goods and services, sectors that make relatively little use of study materials. It is presumed that these items will be available in ample supply and that consumers will offset reductions in spending on consumer durables by spending more on these items. That is, spending in these categories will exceed projected normal spending.

A reduction factor of zero is indicated for a number of sectors. These sectors generally represent necessities and are mainly nondurable goods and services that do not make intensive use of study materials. The zero reduction factors indicate that projected spending is considered essential and that consumer spending will be in line with normal projections.

[24] These particular spending categories correspond to those defined in the economic model used for this 2015 NDS Program study (see Appendix 2b).

[25] Note that spending to replace consumer durables damaged during an attack on the U.S. homeland is considered essential. Similarly, construction to replace damaged assets is considered essential. The reduction factors on Tables A2e.1 and A2e.2 do not apply to such spending on homeland recovery.

Table A2e.1. Percentage Reduction Factors to Eliminate Nonessential Personal Consumption Spending

Personal Consumption Categories[26]		Conflict	Regeneration		
		Year 1	Year 2	Year 3	Year 4
1	New cars	50.0	75.0	75.0	75.0
2	New light trucks	25.0	50.0	50.0	50.0
3	Used cars and trucks	15.0	25.0	25.0	25.0
4	Tires, tubes, accessories	25.0	50.0	50.0	50.0
5	Furniture	25.0	50.0	50.0	50.0
6	Household appliances	25.0	50.0	50.0	50.0
7	Glassware, tableware	25.0	50.0	50.0	50.0
8	Tools and equipment	25.0	50.0	50.0	50.0
9	Video equipment	25.0	50.0	50.0	50.0
10	Photographic equipment	25.0	50.0	50.0	50.0
11	Information processing equipment	25.0	50.0	50.0	50.0
12	Sports equip, guns, musical instruments	25.0	50.0	50.0	50.0
13	Sports & recreational vehicles	50.0	75.0	75.0	75.0
14	Books	25.0	50.0	50.0	50.0
15	Jewelry and watches	50.0	75.0	75.0	75.0
16	Therapeutic appliances	0.0	0.0	0.0	0.0
17	Luggage	+	+	+	+
18	Telephone and fax equipment	25.0	50.0	50.0	50.0
19	Cereals and bakery products	0.0	0.0	0.0	0.0
20	Meat, poultry, eggs, dairy	0.0	0.0	0.0	0.0
21	Fruit and vegetables	0.0	0.0	0.0	0.0
22	Nonalcoholic beverages	0.0	0.0	0.0	0.0
23	Other food products	0.0	0.0	0.0	0.0
24	Alcohol	0.0	0.0	0.0	0.0
25	Clothing, women and children	+	+	+	+
26	Clothing, men and boys	+	+	+	+
27	Other clothing	+	+	+	+
28	Footwear	+	+	+	+
29	Motor vehicle fuels	25.0	50.0	50.0	50.0
30	Fuel oil	0.0	0.0	0.0	0.0
31	Pharmaceutical products	+	+	+	+
32	Other medical products	+	+	+	+
33	Games, toys	+	+	+	+
34	Pets, plants	+	+	+	+
35	Household supplies	+	+	+	+
36	Personal care products	+	+	+	+
37	Tobacco	+	+	+	+

[26] Personal consumption refers to spending by individual consumers. It does not include spending by businesses or the government.

Table A2e.1. Percentage Reduction Factors to Eliminate Nonessential Personal Consumption Spending (continued)

Personal Consumption Categories[27]		Conflict	Regeneration		
		Year 1	Year 2	Year 3	Year 4
38	Magazines, stationery	+	+	+	+
39	Net expenditures abroad by US residents	50.0	75.0	75.0	75.0
40	House rent	+	+	+	+
41	Owner-occupied housing	+	+	+	+
42	Rental value of farm dwellings	0.0	0.0	0.0	0.0
43	Water supply and sanitation	+	+	+	+
44	Electricity	0.0	0.0	0.0	0.0
45	Gas	0.0	0.0	0.0	0.0
46	Physicians	0.0	0.0	0.0	0.0
47	Dentists	0.0	0.0	0.0	0.0
48	Home health care	0.0	0.0	0.0	0.0
49	Medical laboratories	0.0	0.0	0.0	0.0
50	Other medical services	0.0	0.0	0.0	0.0
51	Hospitals	+	+	+	+
52	Nursing homes	+	+	+	+
53	Motor vehicle maintenance	+	+	+	+
54	Motor vehicle renting	0.0	0.0	0.0	0.0
55	Ground transport	+	+	+	+
56	Air and water transport	+	+	+	+
57	Clubs, sport centers, theatres	+	+	+	+
58	Cable and satellite TV	+	+	+	+
59	Photo service, computer repair	+	+	+	+
60	Gambling	+	+	+	+
61	Other services	+	+	+	+
62	Eating and drinking places	0.0	0.0	0.0	0.0
63	Alcohol in purchased meals	0.0	0.0	0.0	0.0
64	School lunches	0.0	0.0	0.0	0.0
65	Accommodations	+	+	+	+
66	Financial services	+	+	+	+
67	Life insurance	+	+	+	+
68	Net household insurance	+	+	+	+
69	Net health insurance	+	+	+	+
70	Net motor vehicle insurance	+	+	+	+
71	Telecom services	+	+	+	+
72	Postal services	0.0	0.0	0.0	0.0
73	Internet access	+	+	+	+

[27] Personal consumption refers to spending by individual consumers. It does not include spending by businesses or the government.

Table A2e.1. Percentage Reduction Factors to Eliminate Nonessential Personal Consumption Spending (continued)

Personal Consumption Categories[27]		Conflict	Regeneration		
		Year 1	Year 2	Year 3	Year 4
74	Higher education	+	+	+	+
75	Nursery - secondary school	+	+	+	+
76	Commercial schools	+	+	+	+
77	Professional and other services	+	+	+	+
78	Personal care	+	+	+	+
79	Social and religious services	+	+	+	+
80	Household maintenance	+	+	+	+
81	American travel abroad	50.0	75.0	75.0	75.0
82	Foreigner spending in the US	50.0	75.0	75.0	75.0
83	Final consumption by nonprofits	+	+	+	+

Construction

The 25 spending categories shown on Table A2e.2 represent various types of construction. Because construction generally makes intensive use of study materials, the reduction factors for some of these categories are quite high, rising to 67.5 percent for residential construction and 50 percent for several commercial sectors. However, all government construction is considered essential as is private construction of transport, communications, and energy infrastructure. In these cases, the reduction factor is zero and spending is presumed to be in line with normal projections.

Table A2e.2. Percentage Reduction Factors to Eliminate Nonessential Private Construction Spending[28]

Construction Categories		Conflict	Regeneration		
		Year 1	Year 2	Year 3	Year 4
1	1 Unit Residential Structures	50.0	67.5	67.5	67.5
2	2 Or More Unit Residential Structures	50.0	67.5	67.5	67.5
3	Mobile Homes	0.0	0.0	0.0	0.0
4	Additions & Alterations	50.0	67.5	67.5	67.5
5	Hotels, Motels, Dormitories	25.0	50.0	50.0	50.0
6	Industrial	25.0	50.0	50.0	50.0
7	Offices	25.0	50.0	50.0	50.0
8	Stores, Restaurants, Garages	25.0	50.0	50.0	50.0
9	Religious	25.0	50.0	50.0	50.0
10	Educational	0.0	0.0	0.0	0.0
11	Hospital & Institutional	0.0	0.0	0.0	0.0
12	Misc. Nonresidential Buildings	25.0	50.0	50.0	50.0
13	Farm Buildings	0.0	0.0	0.0	0.0
14	Mining Exploration Shafts & Wells	0.0	0.0	0.0	0.0
15	Railroads	0.0	0.0	0.0	0.0
16	Telephone & Telegraph	0.0	0.0	0.0	0.0
17	Electric Light & Power	0.0	0.0	0.0	0.0
18	Gas & Petroleum Pipes	0.0	0.0	0.0	0.0
19	Other Structures	0.0	0.0	0.0	0.0
20	Highways & Streets	0.0	0.0	0.0	0.0
21	Military Facilities	0.0	0.0	0.0	0.0
22	Conservation	0.0	0.0	0.0	0.0
23	Sewer Systems	0.0	0.0	0.0	0.0
24	Water Supply Facilities	0.0	0.0	0.0	0.0
25	Broker's Commission (Residential)	7.5	10.0	10.0	10.0

[28] Decrements do not apply to government construction, which is considered essential.

Appendix 2f. Country Reliability Protocol

On behalf of the Defense Logistics Agency Strategic Materials, IDA provided members of the Intelligence Community (IC) with a list of questions (see Table A2f.1 on the following page) to perform their country reliability assessment for the 2015 NDS Program requirements analysis. The analysts were asked to provide scores for more than 175 countries of interest, which were divided into nine geographical regions.[29] The scores elicited from this assessment are used to estimate available supplies of materials from foreign sources.

The analysts within the functional offices who performed these assessments are responsible for tracking materials within countries that support Combatant Command (CCMD) war plans. Other IC members who performed these assessments are assigned to various regional offices, and are responsible for analyzing, among other things, political, military, and economic intelligence for specific areas of the world.

Those assigned to the functional offices were responsible for providing their assessment for Questions #1 and #3 (i.e., ability to supply strategic and critical materials to world markets during the Base Case conflict scenario, and ability/willingness to supply strategic and critical materials in the ongoing, near-term environment absent any conflict, respectively). The individuals working in the regional offices were responsible for providing their assessment for Question #2 (i.e., willingness to sell strategic and critical materials to the U.S. during the Base Case conflict scenario).

[29] In order of appearance on the evaluation matrix, those nine regions are Europe, Eurasia, Africa, Middle East, Central Asia, South Asia, Southeast Asia, East Asia, and the Western Hemisphere.

Table A2f.1. 2015 Country Reliability Protocol and Questions Used in the 2015 National Defense Stockpile Requirements Report

General Notes:

The 2015 NDS Requirements Study Base Case involves the consideration of two possible and independent futures, denoted here as Future 1 and Future 2. Descriptions of these futures are provided under separate cover.

Two different sets of scores to Questions 1 and 2, below, are needed, one set for each future. Please provide your scores to Questions 1 and 2 for the indicated future on the corresponding worksheet. Question 3 applies to general reliability in a near-term environment and is independent of either future. Please provide the scores to Question 3 on the "Evaluation Matrix - Near Term" worksheet.

Question 1: Ability to supply strategic and critical materials (S&CMs)* and other goods and services to world markets during the indicated future conflict scenario.

Please assess—in the context of the indicated future conflict scenario—how able country X will be to supply S&CMs and other goods and services to world markets.

To estimate country X's ability to supply to world markets, consider three distinct environments: (a) general turmoil or inherent instability that may arise in the country regardless of the conflict scenario (e.g., power shortages, transportation breakdowns, labor strife, civil unrest); (b) general turmoil that may be exacerbated by the conflict scenario; and (c) direct constraints imposed by the adversaries on the country's ability to supply to world markets (e.g., reliance on labor force or machine-replacement parts from adversaries, reliance on adversaries for access to world markets, mines are majority-controlled by adversaries). *<u>Note</u>: Ignore direct wartime damage (e.g., bombing damage) in your estimates.*

Please use a scale of 0-100 percent and provide both a low and a high score (i.e., worst-case and best-case situation). To further clarify the scoring, a score of 0 means that country X is completely unable to supply to world markets (i.e., none of its production capability will be available to world markets). A score of 50 means that 50% of country X's production capability will be available to world markets. Finally, a score of 100 means that country X is fully able to supply to world markets (i.e., neither the general turmoil examples provided above nor the constraints imposed by the conflict scenario will impact the country's production capability). *<u>Note</u>: The interpretation of the scoring provided above only pertains to the country's ability to supply.*

Note that Year 1 is the conflict year and Years 2-4 are the three regeneration years. A country's ability to supply to world markets may be more affected during the conflict (Year 1) than during the regeneration period (Years 2-4).

Question 2: Willingness to sell S&CMs and other goods and services to the United States during the indicated future conflict scenario.

Please also assess—in the context of the indicated future conflict scenario—the extent of willingness of country X to sell S&CMs and other goods and services to the United States.

Please use a scale of 0-100 percent, with 100 percent meaning fully willing to sell to the United States and 0 percent meaning totally unwilling to sell to the United States. *<u>Note</u>: For this question, please do not provide a range of values as was done for Question 1.*

This question asks specifically about anti-U.S. sentiment and orientation.

Note that Year 1 is the conflict year and Years 2-4 are the three regeneration years. A country's willingness to sell to the United States may be different during the conflict (Year 1) than during the regeneration period (Years 2-4).

Question 3: General reliability (ability/willingness) to supply S&CMs and other goods and services to the United States in a near-term, ongoing environment.

Please assess—relative to country X's present supply reliability to the United States ("the baseline")—the general reliability (ability/willingness) of country X to supply S&CMs and other goods and services to the United States over the next 2-3 years, given conditions you believe will most likely prevail (as opposed to the two possible future conflict scenarios). Consider factors such as those mentioned in Questions 1 and 2, and also economic and market factors.

Please use a scale of 0-100 percent, with 100 percent meaning fully able and willing to sell to the United States (relative to the baseline) and 0 percent meaning totally unable or unwilling to sell to the United States (relative to the baseline). For Question 3, one value encompasses both ability and willingness. *<u>Note</u>: For this question, please do not provide a low and a high score as was done for Question 1.*

Your Explanations Are Welcome

You are invited (but certainly not required) to provide explanatory notes regarding any factors that influenced your determination of country ability or willingness. Insert comments in the cells of the response spreadsheet or on the Notes worksheet.

* S&CMs are "materials that would be needed to supply the military, industrial, and essential civilian needs of the United States during a national emergency, and are not found or produced in the United States in sufficient quantities to meet such need" (see 50 U.S.C. 98 et seq.)

Appendix 2g. Base Case Scenario Specifics (Classified)

This Section is Classified.

Appendix 2h. Business Sensitive Findings (Proprietary and Classified)

This Section is Proprietary and Classified.

Appendix 3
Market Responses

Appendix 3
Market Responses

Under emergency circumstances, U.S. producers are likely to reduce demands and procure additional material supplies of strategic and critical materials. "Market responses" are defined here as private sector initiatives that are likely to reduce gross shortfalls without government action.

DoD evaluated a range of potential market responses to offset or reduce the estimated Base Case gross shortfalls. DoD selected a conservative approach that involved three elements: conservation/thriftiness, substitution, and an "extra sell" to the U.S. by selected foreign producers. This set of market responses is referred to as DoD's "selected market responses" and they are used to make stockpile recommendations. This section describes the processes implemented for estimating the magnitude of these responses.

Appendix 3a. Thriftiness

Thriftiness is a proxy for conservation. The estimates of the shortfall reductions that result from thrift should be used as an indication of possible conservation effects. Within the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) Sub-step 2D construct, thriftiness is modeled by modifying the material consumption ratios (MCRs) (detailed in Appendix 2), which are used to compute material demand from industrial demand

Thriftiness computations rely upon the same data set used for the computation of MCRs. A revised set of "thrift" MCRs were developed, by using the minimum material consumption value over the three years of the reference period, instead of using the average value. This is apportioned among the industry sectors in the same manner as for the regular MCRs. The average economic output data over the reference period are used. The resultant ratios (material used by sector divided by economic output of that sector) form a set of MCRs that are lower than the regular MCRs. These lower MCRs are then applied to the industry demands to determine a lower set of material demands. The lower MCRs are a way of quantifying a material conservation approach. This type of conservation is postulated to occur during the scenario period as a market response, reflecting a determined effort by material users to consume less.

Appendix 3b. Substitution Protocol and Results

Another possible market response for mitigating shortfalls of materials during a national emergency is the use of substitutes to meet demands for applications. This section evaluates the extent to which the market response of substitution can be used to offset the gross shortfalls in the 2015 National Defense Stockpile (NDS Program) Base Case. The general approach is to identify the most promising substitute materials for each of the strategic and critical materials' major application areas and then evaluate the utility and availability of the substitutes for each application area.

It is assumed that in the face of material shortages caused by the occurrence of the Base Case scenario, industry would turn to substitutes to enable it to continue to produce goods and services for its customers. The substitution results—the fraction of material demand for each material that could be satisfied by substitutes—are used in the net shortfall calculation process that yields the shortfalls that must ultimately be mitigated by government action.

Approach

The first step in the approach for considering the potential market response of substitution is to identify, for each of the shortfall materials, the most promising substitute materials, by application area. The second step is to estimate and justify how much of the Base Case shortfalls, material by material and application area by application area, can be mitigated through substitutions that do not have any significant adverse performance effects or create other shortfalls. This step involves not only assessing the utility of possible substitutes but also their availability while considering everything that might have to be done to bring them into use. Considerations for employing substitute materials include the development of enabling capabilities like product design change, design certifications, production facilities, specialized labor, and material supplier networks.

Substitution Assessment Protocol

To identify and evaluate candidate substitutes for each of the Base Case shortfall materials, the Defense Logistics Agency Strategic Materials employs a protocol of questions that are provided to subject matter experts. This protocol was developed and updated over the past several years. It was first used to assess the substitutability of shortfall materials for the FY2013 NDS Program Requirements Report and its development is discussed in more detail in that document.[30]

The protocol, summarized below, was provided to individual subject matter experts at the U.S. Geological Survey (USGS), the Institute for Defense Analyses (IDA), and others in government, industry, and academia, who answered its questions for each shortfall material. Their answers were collated and supplemented as necessary with further data gathered from additional subject matter experts and the materials literature. The information was then synthesized to produce estimates of the extent to which substitution could mitigate the shortfalls for each of the shortfall materials in the Base Case Scenario.

The protocol's approach to the substitution assessment is to examine each strategic material individually. For each material, the expert is asked to consider each of its major areas of application and assess whether there are other materials that could, at least to some degree, substitute for the material in question in each area. It is the nature of the uses of materials (in most cases here, chemical elements) that one material can be a substitute for another material for

[30] Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, *Strategic and Critical Materials 2013 Report on Stockpile Requirements* (January 2013), Appendix 9.

some applications but not for others. The experts are also asked to consider whether functional substitutes could be utilized by the market to meet demands for shortfall materials in their various areas of application. A functional substitute is a product that performs the same function as products using the shortfall material but via a different approach. For example, an LED lamp is a functional substitute for a compact fluorescent bulb. The general approach of the protocol is to identify the most promising substitute materials or functional substitutes for each of the strategic and critical materials' major application areas and then evaluate the utility and availability of the substitutes for each application area.

It is recognized that substitutes may not be perfect. Even within a single application area, they may be suitable for only some of the uses of the strategic material in question. They may require the acquisition of additional capital or labor before being usable on a significant scale. They may also impose costs on product manufacturers or users such as production costs, operating costs, worker health and safety obligations, or environmental impacts. Nevertheless, the intent was to identify even partial or imperfect potential substitutes so that the Department of Defense (DoD) could determine the extent to which industry might use substitutes to mitigate the effect of strategic material shortfalls.

Finally, based on the significant body of research on substitution that the NDS Program has supported to date, substitutes tend to be available more so for civilian applications than for military applications. That is because military systems tend to be complex and military applications tend to be more demanding in terms of performance.[31] For some systems, no alternative to the material used in the design is suitable. For many other systems, the design certification process is so onerous and time consuming that the substitute material, even if theoretically acceptable in terms of performance, could not be brought into use in time to mitigate a shortfall during the scenario in question.[32] Therefore, the substitution assessments conducted for this report focus on materials with civilian sector shortfalls (i.e., shortfalls that would leave the United States with insufficient material to meet civilian sector demands). The sections below discuss each of the questions asked of the experts by the substitution assessment protocol.

1. Identification of Potential Substitutes

The first step in the protocol was to identify candidate substitutes for each major application area of each of the Base Case shortfall materials. For each strategic material for which potential substitutes are to be identified, the experts were provided its major application areas in the

[31] System complexity can constrain the design option space available for the use of alternative materials with different physical characteristics.

[32] There are exceptions to this—some defense-related products are similar to their civilian counterparts and hence would be amenable to having demand for them met through the use of substitutes. But the demands represented by those applications are generally very small compared to the civilian sector demands for a material, so they were not evaluated for this report.

United States. The application areas were mostly taken from the database used to assess material demands by industrial sector for NDS Program analyses.[33] The experts were asked to identify each potential substitute material or functional substitute that could replace the shortfall material in each of its application areas. It was made clear that one material may be a suitable substitute for another material in one application area but not another. For those cases, the experts were asked to indicate the specific application areas of the strategic material in question for which a potential substitute material could be suitable.

2. Assessment of the Extent to Which Each Substitute Can Be Used

The next step in the protocol was the determination of the extent to which each substitute candidate could be used for the shortfall material in question in each of its major application areas. The experts were asked what fraction of the strategic material used in each application area could be replaced by the substitute. The intent of this question was to capture the fact that while some material might be a suitable substitute for a strategic material used in an area of application, it might only be suitable for some fraction of the uses or products within that area. This could be because of unique properties or particularly high performance required for certain specific applications within any given area of application.

The protocol for this cycle also emphasized that the question was asking for the market response to the shortfall, rather than a government response. This was to capture what industry would do in response to a shortfall before the government intervened to mitigate or help mitigate it.

For this report, the experts were also asked to provide upper and lower (conservative) values for each of these estimates. The NDS Program did this out of recognition that there is uncertainty in estimating market-based responses to substitute material demands. It also helped identify conservative estimates of material substitutability.

3. The Nature of the Substitution to Be Made

The next question in the protocol concerned the nature of the substitute and its application. For each strategic material, each of its major application areas, and each candidate substitute material, the experts were asked to explain whether the substitute would replace the strategic material on a one-for-one basis or it would replace the strategic material in similar but not identical products (or would the substitute be a different product or technology altogether).

Some substitutes, like alloying agents, can be used in identical products on a one-for-one or nearly one-for-one basis. Others require the product design to be modified somewhat so that the new product is similar but not identical to the one using the strategic material that is being replaced. Still others are used in products that perform the same function as products using the

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[33] The major application areas in the United States for each material and the fractions of the total U.S. demand of each material used in them are provided by the USGS, the Department of Commerce, and other subject matter experts as part of the NDS Program analytical process.

shortfall material but via a different approach. This question was intended to gain a better understanding of the nature of the substitution that would be made.

4. The Amount of the Substitute Material Required and Other Impacts on Materials Usage

This question addressed the quantity of substitute material required to replace the shortfall material. For each strategic material application, the experts were asked how much of the substitute material would have to be used to replace each unit mass (e.g., tr.oz., kg, ton) of the strategic material in that application. For each of those instances, they were asked whether the change from the strategic material to the substitute also requires changes to the use of other materials in the production process for the products containing the substitute.

In considering the substitution of other materials for strategic materials that might experience shortfalls under certain conditions, we needed to ascertain how much of the substitute materials would be required so that we could assess whether any of the substitutes might also experience shortfalls. Substitution possibilities that would themselves create or exacerbate material shortfalls were excluded from consideration in this assessment. We also assessed whether changing to substitutes could change the consumption pattern for other materials used in the production of the products containing the substitute (like solvents or materials that would come into contact with the substitute) sufficiently to significantly affect the consumption of strategic and critical materials in the United States.

5. Key Enablers Needed to Facilitate Substitution

The next question in the protocol concerned supply and production-related capabilities needed to enable the use of the substitutes. The relevant experts were asked what would be required to enable each substitute to be used for each potential application being considered.

In some cases, one material may be substituted for another (or one product for another) immediately, without anything new required in the supply chain that would produce the products. In other cases, however, certain key enablers are needed before the substitution can take place. For example, there may be a need for new product designs or, in the case of regulated industries (like defense), government design certifications. Certain customers may have requirements that specify the use of particular materials in products. There may be a need for new or modified production facilities or an expansion of capacity at existing facilities. There may be a need for more labor or possibly retrained labor to operate the supply chain. There may be a need for new networks of material suppliers to provide material feed stocks, including the substitute material. There may be legal limits that restrict the use of certain substitutes.

This question aimed to capture what was necessary, beyond a supply of substitute materials or products, to enable the substitutes to be used. The responses to this question help the NDS Program understand why it might be more or less difficult to use substitutes for the application in question and how long it would take to bring the substitute into use. If significant enabling capabilities are needed to bring a substitute into use, it will probably take longer to do so. Reponses to this question also serve as part of the basis for the estimated substitutability fractions and the delay estimates.

6. Time Frame in Which Each Substitute Can Be Used

The next question was how quickly the substitute could be brought into use to a significant extent. The experts were asked how soon, in the event of a crisis or supply disruption, the substitute could be brought into use. They were asked specifically whether each substitute could be used immediately, in the short term (i.e., one to six months), in the medium term (i.e., six months to two years), or in the long term (i.e., longer than two years).

The intent of this question was to determine how soon, in the event of a sudden and possibly unexpected crisis and in light of everything that would need to be done to facilitate it, substitutes could replace the shortfall material in each of its application areas. A longer time horizon can allow greater use of substitutes as new products are designed specifically to avoid materials in short supply. But the shorter time horizon available to respond to a crisis can pose a barrier because of the lack of product designs, production facilities, and other necessary enabling capabilities.

In the Base Case Scenario, almost all of the shortfalls occur only in the first year of the scenario. Thus, as shown later when discussing results, the only substitutes that would be useful in the Base Case (with one exception) are those that would be available in the short term. But even for those substitutes, materials or products that are available in the market now would be able to substitute for shortfall materials to a greater extent than those that require even a few months to be brought into use to a significant extent.

7. Additional Costs or Consequences Incurred in Using the Substitutes

Similar to the question about enabling capabilities, this question asked about additional costs or consequences involved in the use of substitutes for shortfall materials. The experts were asked what additional costs or burdens might be incurred if the substitutes were used?

Materials tend to be used where the market determines that their application is optimal (relative to other material choices) with respect to performance (considered broadly) and cost. Thus, substituting one material for another, or one product for another, in a given application typically imposes one or more burdens in the life cycle of the product, even if only to shift the balance between cost and performance. Such potential burdens can include: production costs, product operating and maintenance costs, product lifespan limitations, waste disposal or recycling costs, environmental impacts, energy usage, health and safety obligations, risks arising from foreign supply chains, and the cost or burden of switching back to the original material after the supply disruption is over. This question asked for the identification of each such burden that would be imposed if a substitute replaced the strategic material in question in each of its areas of application. Responses to this question also help the NDS Program understand why it might be more or less difficult to use substitutes for the application in question. If there are many or significant costs associated with using a substitute, it suggests that the substitute may not be used or may not be used very extensively in practice.

8. Final Evaluation of Overall Substitutability

The last question in the protocol asked about the overall attractiveness of using each of the candidate substitute materials in each of the shortfall material application areas being considered. The experts were asked, given all that they understand regarding the costs and benefits of potentially replacing strategic materials with a substitute in a given application, how attractive would the substitution be on a linear 1–10 scale (with a 1 being a highly unattractive, just barely usable substitute, and a 10 being a nearly perfect, minimal-burden substitute).

The intent of the overall rating was to allow the NDS Program, other analysts and modelers, and potentially policy-makers and their staffs, to quickly get a sense of the extent to which material substitution could mitigate the risk of a shortfall of one or more strategic materials in their various applications. It was understood, however, that final decisions by the government on whether to rely on substitution to mitigate risk as a matter of policy would likely turn on consideration of all of the available information concerning the costs and benefits and potential further risks related to doing so. Decisions by the private sector to turn to substitutes in the face of a shortage would also be made firm by firm based on the firms' individual circumstances in the market and their beliefs as to the costs and benefits of doing so.

Sources of Data

As noted above, to collect the data needed to perform the substitution assessment, the protocol of research questions just discussed was developed and provided to individual experts at the USGS, IDA, and others in government, industry, and academia. Their answers were collated and then supplemented with further data gathered from additional experts and the materials literature. Those data were synthesized to estimate the extent to which substitution could mitigate Base Case Scenario material shortfalls.

Subject matter experts from the following organizations were consulted in collecting data for the substitution assessments:

Table A3b.1. Organizations Consulted in Conducting Substitution Assessment

USGS
Defense Logistics Agency Strategic Materials
IDA
Department of Defense (Air Force Materiel Command/Air Force Research Lab)
Department of Defense (Army Research Lab)
Department of Energy (Headquarters)
Department of Energy (Ames Laboratory)
Department of Commerce
Central Intelligence Agency
Office of Science and Technology Policy
National Academy of Sciences (Committee on Critical Mineral Impacts on the U.S. Economy, Committee on Earth Resources, Board on Earth Sciences and Resources)
Massachusetts Institute of Technology
Colorado School of Mines
GE Global Research
Molycorp, Inc.
Arnold Magnetic Technologies Corp.
Electron Energy Corp.
Rare Earth Industry and Technology Association
The Boeing Company
Pratt & Whitney
The Rhodia Group
The Minerals, Metals & Materials Society
Umicore Optical Materials

Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls

For each shortfall material and each of their major application areas, the responses to the research protocol were collated to identify the substitute materials, the fraction of U.S. demand for the shortfall material for that application that the substitutes could (collectively) meet, the additional enabling capabilities (if any) that would be required to use the substitutes, and the other costs and consequences (if any) of using the substitutes. Where the information provided by the experts in their initial responses was not sufficient to answer those questions, it was supplemented with further information collected from the responding experts, additional experts, or the literature. The table below provides collated data for each of the Base Case shortfall materials and their application areas. Where the experts provided us with ranges of substitutability assessments, we used the lower values. Application areas with substitutes that are useable in the first year of the scenario are highlighted in dark gray. Areas with substitutes usable only after the first year are in light gray. Those substitutes in light gray are not usable to mitigate shortfalls in the Base Case Scenario. Application areas with no substitutes identified are in white. The total fraction substitutable is the fraction substitutable for the material overall, during the first year of the scenario. It is calculated as the sum of the products of the fraction of demand attributed to each application area and the substitutability fraction for each area. It is indicated in the table in the first row for each material, in dark gray, unless all of the material's substitutes are usable only in the second and later years of the scenario, in which case the total fraction substitutable is indicated in light gray. The table also summarizes the enabling capabilities required to bring the substitutes into use and the costs and/or consequences of using the substitutes (where nothing is indicated, the costs/consequences are not noteworthy). As noted above, substitution possibilities that themselves showed or would create shortfalls are not considered as mitigation options in this analysis.

Table A3b.2. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Aluminum Oxide, Fused Crude	Abrasive products	Silia, garnet, chromium (III) oxide, Emery, aluminum-zirconium oxide, metallic abrasives, flint, quartz	90	58	52	None	Significantly higher material costs, more frequent changes of abrasive product
	Clay building material, refractory manufacture		7	0			
Antimony	Plastics and resins (flame retardants)	cadmium zinc alloy for plastic; aluminum trihydrate and magnesium hydroxide for retardant; Boron	32	18	26	many substitute alternatives already in wide use, minor process redesign for some	Higher material costs, slightly diminished performance
	Synthetic rubber	Selenium, tellurium	19	65		Minor process redesign	Higher costs
	Storage batteries	Calcium, selenium	19	44		Calcium replacing antimony now	

A3b.2. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
CSM	Automotive uses (hose/tubing/belts)	Other synthetic rubbers	22	90	93	Material supplier network	None
	Industrial products (hose/belts/seals/tank linings)	Other synthetic rubbers	22	90		Material supplier network	None
	Construction applications (roofing and geomembranes)	Other synthetic rubbers, thermoplastic polyolefin (TPO)	29	100		Material supplier network	None
	Wire and cable (sheathing)	Chlorinated Polyethylene (CPE), polyvinyl chloride (PVC), polyethylene	16	90		Material supplier network	None
	Other (molded goods, coatings, etc.)	Chlorinated Polyethylene (CPE), polyvinyl chloride (PVC), polyethylene	11	90		Material supplier network	None
Dysprosium	Phosphors		17	0	8		
	Permanent magnets	Electromagnets	80	10		None	Higher system operating costs

A3b.2. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Europium	Phosphors, Lighting	LEDs; accept lower quality lighting with less REs added	85	15	13	None	Lower quality lighting
Fluorspar, Acid Grade	Hydrofluoric acid production		95	0	5		
	Primary aluminum production	Imported aluminum fluoride, cryolite, and crushed tapped bath	5	100		None	Potential health, safety, or environmental costs, reliance on imports

A3b.2. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Germanium	Semiconductors, electron tubes, solar cells	Silicon, Gallium arsenide	43	10	9	None for substituting lower performing solar cells (already in use)	Lower conversion rates for solar cells, increase in operating costs
	Infra-red optics	Chalcogenide glasses, zinc selenide	21	30		Product designs, production facilities, material supplier networks, specialized knowledge	Zinc selenide health hazard
	Communication/ energy wires/cables (fiber optics)	Titanium dioxide, plastic optical fiber (fluorinated), Rare earth doped phosphate glass	19	17		Redesign	Lower capability, higher production and energy costs
	Pharmaceutical/ medicine		5	0			
	Primary nonferrous metal smelting		5	0			
	Watches, clocks, measuring and control devices	Other phosphors, many types	3	50		None	Lower performance

A3b.2.Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Graphite	Refractories	Synthetic graphite[a]	W[b]	20	13	None	Increased costs
	Drilling mud		W	0			
	Brake linings	Organic composites	W	50		Possible capacity increases	Increased costs

[a]Synthetic graphite is produced by heating carborundum, petroleum coke mixed with coal tar pitch, or powdered petroleum coke to high temperatures in appropriate processes.

[b]W = withheld as proprietary

A3b.2. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Lanthanum	Storage batteries	Cerium, other batteries (NiCd, Li-ion, alkaline	30	75	52	None	Higher costs
	Motor vehicle parts (catalytic. converters)	Cerium	22	56		Reformulated design of some catalytic converter wash coats	
	Iron and steel alloys	Cerium, MgFeSi alloys	20	56		New methodologies for additions.	Higher costs, possible product quality impacts
	Petroleum refineries	REE-free FCC catalysts	11	56		Increased production capacity	Higher costs, lower efficiency
Magnesium	Reducing agent for production of titanium and other metals	Sodium, aluminum	34	4	40	None	None
	Aluminum alloys (packaging, transportation, etc.)	Other aluminum alloys, plastics, steel	33	60		Equipment adjustments; increased capacity	Higher costs, product defect rates, increased product weight
	Casting and wrought products	Aluminum, other aluminum alloys, zinc, steel, plastics	18	75		Some equipment modification, product redesign, new capacity	Increased product weight
	Desulfurization of iron and steel	Calcium carbide	11	50		Expanded capacity	Process safety issues

A3b.2. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Manganese Metal, Electrolytic	Metal cans/ containers	Aluminum alloys, steel; or plastic/glass containers	53	19	12	None	Some small risk from using lower strength materials
	Other general purpose machinery	Aluminum alloys, Steel, Silicon; delay replacing and upgrading machinery	13	8		Some minor redesign	Higher costs, lower productivity
	Broadcast/ wireless comm equipment		7	0		None	
	Motor vehicle parts	Aluminum	5	15		None	Minor lower performance
Rubber, Natural	Tires & Inner Tubes	Synthetic rubbers	53	100	100	Some product redesign	Some loss of performance
	Footwear and Other Leather Products	Synthetic rubbers	33	100		None	
	Gasket Packing/Sealing	Synthetic rubbers	8	100		None	
	Hose and Belting	Synthetic rubbers	6	100		None	

A3b.2. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Silicon Carbide	Abrasive products	Silica, diamond, garnet, chromium(III) oxide, alumina-zirconia, flint, quartz	26	33	20	None	Abrasive may not last as long, more frequent replacement, more expensive
	Motor vehicle parts	Ceramics, steel, other metals	20	40		None	Higher operating costs, shorter product life span
	Clay bldg. materials and refractory	Silica nitride, boron carbide, titanium ceramics	9	15			
	Farm and industrial machinery		7	0			
	Hand tools	silica, industrial diamonds, garnet, chromium(III) oxide, alumina-zirconia, flint, quartz; delay replacing and upgrading machinery	6	30		None	Higher material and labor costs

A3b.2. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Tantalum	Other electronic components	Niobium, aluminum	69	13	12	Minor redesign may be needed	Larger and heavier capacitors
	Surgical and medical instruments, appliances	Niobium, titanium, zirconium; delay replacing and upgrading instruments and appliances	13	23			Less corrosion/ contamination resistance, shorter product life, higher cost
	Aircraft engines and engine parts	Other materials can substitute, but not assumed due to lower performance	9	0			
	Other industrial machinery	hafnium, tungsten, niobium, molybdenum; delay replacing/ upgrading machinery	4	8			

A3b.2. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Tin	Metal cans/containers	Aluminum and plastic	20	75	23	None	May be some product loss from damaged containers
	All other electronic components	Lead primarily; indium, copper, silver also	20	8			Environmental damage from use of lead based solder. Lead based solder cheaper and as or more effective. Non-lead substitutes much more expensive, limited supplies
	Ornamental/ architectural metal	Lead, steel	9	75			Environmental and health considerations if lead used; otherwise lead replacements better. Steel only disadvantage is higher cost
	Pharmaceutical/ medicine		7	0			
	Motor vehicle parts		7	0			

A3b.2. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Tungsten	Special tools/dies/jigs/ fixtures/metal cutting/ forming/machine tools	Cermets, ceramics, chromium, titanium	60	18	23	Changes in heat treatment and process, but other methods already exist, some better	Less wear resistance and hot hardness for steel, but cermets are replacing tungsten carbide in saws and other cutting tools due to superior wear and corrosion properties
	Steels (FeW), Alloys	Molybdenum steel, nickel, other alloys	19	47		Production (heat treatment) facilities	Minor loss in product performance or higher cost
	Industrial molds, mill products, lamps, other specialty applications	Lead, depleted uranium, molybdenum	16	20		Relaxation of regulations against lead usage, handling of radioactive material	Minor loss in product performance or higher cost, environmental and health considerations if lead or depleted uranium used

A3b.2. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (concluded)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Yttrium	Phosphors, lighting	Incandescent lights and LEDs, alternative fluorescent lamp phosphors	55	25	15	Most of these uses have alternatives used before; LEDs are replacing now	Some higher acquisition and operating costs, energy usage, relaxation of energy regulations on the use of older lighting technologies or less light
	Ceramics		14	0			
	Auto catalysts	Platinum, other catalysts	6	25		Minor redesign	Potentially increased air pollution if regulations relaxed
Yttrium Oxide	**Withheld**						

Results and Observations

Figure A3b.1 below shows the fraction of total U.S. civilian demand for shortfall material in the Base Case that could be met, collectively, by substitutes. The bars show the substitutability, for the materials evaluated, in the first year of a crisis or conflict. The figure shows a broad range of results. Some shortfall materials, like aluminum oxide, CSM, and natural rubber, are highly amenable to the use of substitutes. Much of their demand could be met with substitutes with little or no delay. Other materials, like antimony, silicon carbide, and tin, are partly amenable to the use of substitutes. Even limited substitution may be enough, however, to eliminate most or all of a projected shortfall because the shortfalls typically amount to modest fractions of annual demand for the materials studied. A few materials, like dysprosium and fluorspar, are only slightly substitutable. In those cases, shortfalls could remain even after substitution was utilized to the full extent possible.

It should be noted that these results reflect the usable substitutes that have been identified by research to date. Upon continuing this research one might discover additional substitutes for the shortfall materials in their various applications. That would increase the fractions of total demand that could be met by substitutes that are shown in the figure.

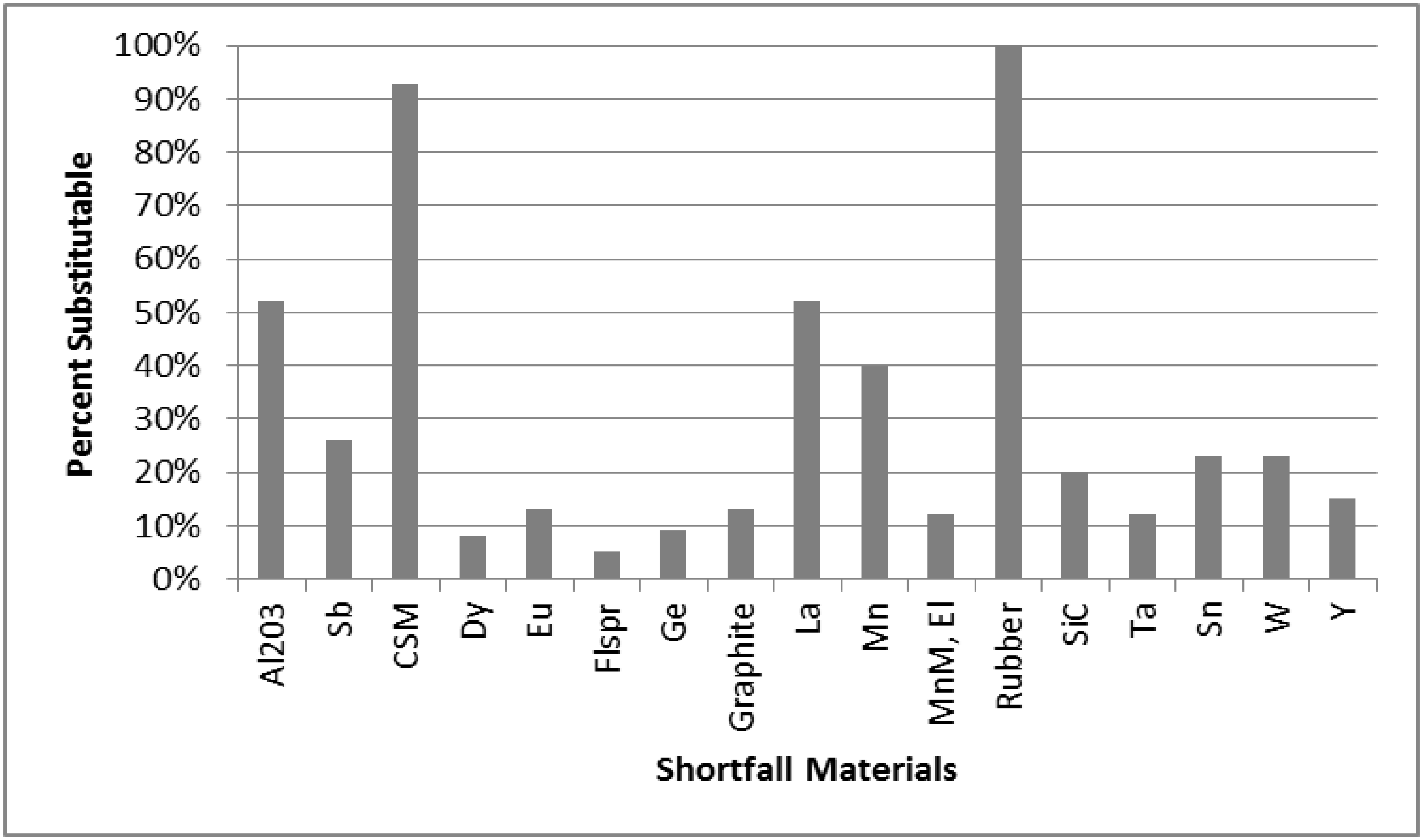


Figure A3b.1. Predicted Market Response of Substitution for Base Case Shortfall Material

Conclusion

The market response of substitution has significant potential to mitigate material shortfalls during a conflict or supply disruption crisis. Often, alternatives are available to meet material demands but under ordinary circumstances they are not used because they are somewhat suboptimal from the market's perspective on cost-effectiveness—they are more expensive than the material currently in use for the application in question, they do not perform quite as well as the material currently in use, or their usage imposes other avoidable costs like product operating costs or energy usage costs. Nevertheless, during a conflict or crisis, when materials may not be available as they are today, substitute materials or substitute products can be available to meet demands. Analysis of the shortfall materials for civilian applications for the 2015 NDS Program Base Case scenario shows that substitutes could mitigate shortfalls, at least in small part, for all of them. Because substitution for civilian materials applications is assessed to be part of the market's response (rather than a government response) to potential material shortages, substitution requires no government expenditures (beyond those for the strategic materials planning process). Substitution is not available for all material applications, particularly defense applications that demand the highest material performance or the use of only qualified materials. But where it is available, substitution is a powerful material shortfall mitigation option compared to other options, like stockpiling, that may require government action and expenditure.

Appendix 3c. Extra Sell

This appendix concerns the supply side market response shortfall mitigation option that involves preferential U.S. access to previously unused foreign production capacity of key strategic and critical materials, thought of as an "extra sell" to the U.S..

Market Shares

The United States is not in general the only country that demands a material. In a conflict scenario, allies have legitimate uses of the material, and unfriendly countries might be able to outbid the United States for some of it on world markets. Thus the United States cannot necessarily obtain all the foreign supply. In the context of the models, the term "market share" factor refers to the fraction of foreign supply the United States can obtain. The market shares for the different materials are inputs to the model; they vary by material but not country. The most commonly used approach for developing market shares is to take the ratio of the U.S. gross domestic product (GDP) to the total of the GDPs of all the countries, including the United States, that demand that material. (GDPs of countries involved in the conflict scenario can be decremented to account for war damage). GDP can be considered a measure of the ability of the United States to bid, relative to other countries. An alternative way of computing the market share is to take the ratio of (current) U.S. imports to non-U.S. production; a third way is to use the share of foreign production that would make the sum of available U.S. and foreign supply equal to demand in peacetime for the first scenario year. For the Base Case, the maximum of these three quantities is used.

Note that the market share factor operates in addition to the other foreign supply decrement factors of war damage, infrastructure reliability, anti-U.S. sentiment, and shipping losses. In the Base Case data, most of the market shares are in the range of 20 to 30 percent.

Estimated Production vs. Unused Capacity

It is often the case that a production facility is not being operated at full capacity. The amount actually produced is uncertain and often dependent on economic factors, while the amount of capacity, including production plus unused capacity, is more stable. The specialists at the U.S. Geological Survey provide estimates of future capacity for each producing country for a number of years into the future, including the course of the scenario period. In this context, capacity represents readily available extra production that can be brought online in a few months with little or no extra investment—perhaps simply by adding an extra shift.

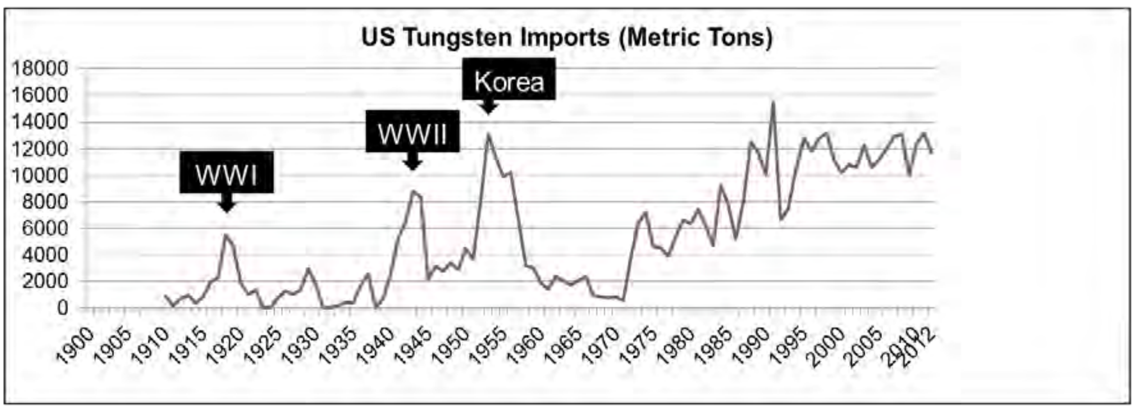
In an emergency scenario in which demand for the material increases and supply might become tight, prices might become very high (see below). This would stimulate friendly countries to start exploiting their previously unused capacity, and some of this extra production is assumed to be available to the U.S. The Base Case assumption is that the United States can access its market share percentage of the total available foreign capacity. The total available foreign capacity is defined as the full capacity in the second, third, and fourth years of the scenario. In the first year, it is somewhat less, to allow for time to ramp-up to full capacity. This is a method of estimating the supply that the U.S. obtains under Base Case conditions, and does not imply that foreign producers actually will operate at the available capacity level.

The Extra Sell or Expanded Market Share Concept

But it is certainly reasonable that in a national emergency scenario, the U.S. might be able to obtain even more than its Base Case share of previously-unused foreign capacity. Funds might be available to pay foreign producers to utilize some or all of their excess capacity, with the proviso that the United States obtains preferential access to the output of the portion of capacity that previously was unutilized. This concept can be referred to by the phrases “extra sell” or “expanded market share”.

Preliminary analysis of a representative shortfall material such as tungsten provides historical evidence of extra sell-driven import spikes during past conflicts (World War I, World War II, and Korean War). In reviewing the shortfall materials addressed by the extra sell market response posited for the 2015 National Defense Stockpile (NDS Program) Base Case, imports of these materials were consistently higher during these conflicts, often exhibiting sharp swings that corresponded with the beginning and cessation of hostilities. Furthermore, in the example of tungsten, positive linear correlations can be found between material prices, world production and U.S. imports.[34] An example of these events is depicted in the figures below (Figure A3c.1 and Figure A3c.2).

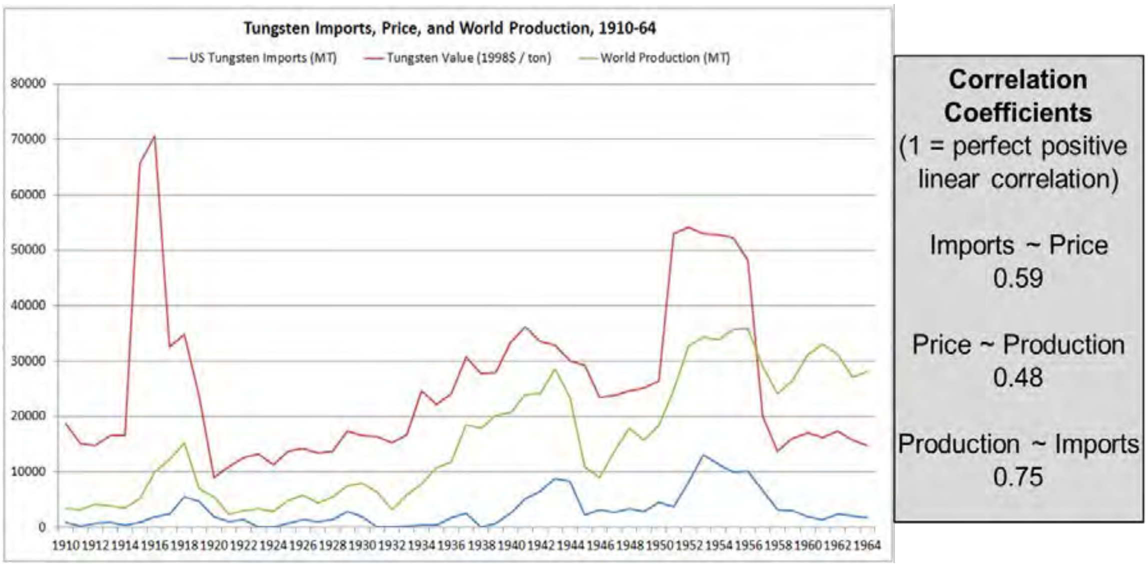
- Wartime demand in WWI, WWII and Korea led to higher prices, foreign producers ramping up output, and spikes in US imports



US Geological Survey: "During World War I, the first widespread use of tungsten in armaments… stimulated production in the United States and launched the Chinese tungsten mining industry. Rearmament in the 1930's and interruptions to supplies from Burma and China during World War II led to the opening of new mines in Brazil and boosted production in Bolivia, Japan, and Spain. **In the 1950's, during and after the Korean War, the U.S. stockpiling program spurred the development of tungsten deposits, especially in Australia, Peru, Portugal, and the United States**."

Figure A3c.1. Tungsten Import Spikes during Wartime

[34] Institute for Defense Analyses (IDA), "US Market Responses to Wartime Material Demands, A Historical Assessment," draft briefing for Defense Logistics Agency Strategic Materials, August 26, 2014. Data drawn from US Geological Survey (USGS) 2014 Online edition of *Historical Statistics for Mineral and Material Commodities in the United States,* downloaded August 18, 2014, http://minerals.usgs.gov/minerals/pubs/historical-statistics/#data.



IDA, "US Market Responses to Wartime Material Demands, A Historical Assessment," draft briefing for Defense Logistics Agency Strategic Materials, August 26, 2014."

Figure A3c.2. Tungsten Correlation Between Price, World Production, Imports

Implementation in the Modeling Process

Consider the projected available supply capacity for a given material from a given country in a given year. Partition this capacity into an amount corresponding to production and an amount corresponding to unused capacity. Of the former part, the United States is assumed to be able to get the "regular" market share, as described above. Of the unused capacity, the United States gets a share value that is *x percent* of the way between the regular share and all of the unused capacity. This share value can be denoted the expanded market share. The portion of the unused capacity that the United States gets, above the regular market share, can be thought of as the "extra sell" material.

The value *x*, which can be referred to as the expansion factor, is an input to the model that does not depend on material or country. It can vary from 0 to 100 percent. A value of zero for *x* corresponds to no expanded market share, the regular share being used across the board. In the Base Case, *x* was set to zero. The Stockpile Sizing Module (SSM) inputs can be set so that only certain selected material/country combinations are considered for the extra sell possibility (the expansion factor *x* applies only to those combinations). For the market response case, only eight specific countries are considered, as discussed in subsequent sections of this appendix; the expansion factor *x* was set to 50 percent.

Example of the Extra Sell Concept

An example might make the procedure clearer. Figure A3c.3, below, provides an illustration of the extra sell concept. The computations are performed separately for each combination of material, country, and year. So imagine Figure A3c.3 as treating one such combination. Assume that the peacetime production would be estimated at 600 tons but that 400 tons of extra, previously-unused capacity is available that year. Let the regular market share be 25 percent. In an emergency, the full capacity of 1,000 tons is assumed to be potentially available on world markets, but not necessarily to the United States. Without the extra sell, the modeling process postulates that the United States would be able to obtain 25 percent of 1,000 tons, or 250 tons. This could be partitioned as 150 tons of the estimated production plus 100 tons of the previously-unused capacity. Using the expanded market share, with a parameter *x* equal to 50 percent, the total U.S. share of the 400 tons corresponding to previously-unused capacity would be $0.25 + 0.5 \times (1 - 0.25)$, or 62.5 percent of the 400 tons of additional capacity (i.e., 250 tons). The idea is to go halfway between the regular market share and getting all of the previously unused capacity. This share of 62.5 percent can be partitioned as the regular share plus the extra share, i.e., 25 percent plus 37.5 percent. The amount 37.5 percent of the 400 tons of previously-unused capacity, i.e., 150 tons, can be considered the amount of extra sell.

The different rectangles in the figure show the partitioning of the total capacity into the various quantities of interest. The total amount the United States obtains is the sum of:

- its regular share of estimated peacetime production (150 tons),
- its regular share of previously-unused capacity (100 tons), and
- the extra sell amount (150 tons).

In the example, this adds up to 400 tons, as opposed to 250 if the extra sell option had not been allowed. (This amount might then be subject to conflict-related decrements such as war damage, as mentioned earlier).

The previously-unused capacity is to be regarded as the previously-unused capacity that is potentially available on the world markets, *in the particular year under consideration.* During the first year of the scenario, it might take some time for a producer to ramp up to capacity, so the previously-unused capacity that is potentially available in the first year might be less than that in subsequent years.

Parameters	Example value	
Total capacity	1,000	(tons)
Estimated peacetime production	600	
Previously-unused capacity ready for use	400	
Regular U.S. market share	25%	
Expansion factor *x*	50%	

Total U.S. share of previously unused capacity = .25 + .5*(1-.25) = .625

Extra sell percentage = .625 – .25 = .375

(Regular) U.S. share of estimated production	.25*600	150
Share of estimated production going to other countries	.75*600	450
Regular U.S. share of previously-unused capacity	.25*400	100
Extra sell = additional U.S. share of previously-unused capacity	.375* 400	150
Unused capacity that might remain unused or go to other countries	.375* 400	150
Total to U.S.	150+ 100+ 150	400

(indicated tonnage amounts are proportional to the areas of the rectangles)

Figure A3c.3. Extra Sell Concept: Preferential U.S. Access to Foreign Unused Capacity

Foreign Country Cooperation

It is unrealistic to assume that every country in the world would agree to engage in extra sells with the U.S. Also, it is impossible to say with certainty whether any particular country would cooperate with the U.S. in a future emergency. Yet for modeling purposes, NDS Program needs to restrict extra sells to a set of countries. NDS Program approached the construction of this set with careful deliberation. NDS Program surveyed experts, investigated historical precedents, and considered current political and diplomatic factors. The result is the following policy. The NDS Program models extra sells for those countries for which the U.S. has an Overview of Security of Supply Arrangement (SOSA) or a Memorandum of Understanding (MOU). There are seven countries that meet this criteria. In addition, the NDS Program includes Japan as an 8th potential extra sell country due to recent overtures by that country's government regarding their willingness to loosen export controls for military sales.

The U.S. currently has SOSAs with six countries: Australia, Finland, Italy, the Netherlands, Sweden, and the United Kingdom. SOSAs are bilateral arrangements the U.S. Department of Defense has negotiated with a select set of countries to ensure mutual supply of defense goods and services. Extra sells would often not explicitly take place within the construct of a SOSA, as SOSAs only cover military goods and services. However, the fact that a particular country has signed such an agreement is a good indication of their willingness to cooperate with the U.S. in a national emergency.

The U.S. has an agreement with Canada called the Memorandum of Understanding on Priorities and Allocation Support Between the United States Department of Commerce and the Canadian Public Works and Government Services Canada. This is similar to a SOSA, but more flexible. The MOU was established in 1950 with the outbreak of the Korean War. The intent of the MOU was to leverage the two countries' mobilization experience during World War II. This MOU has been updated several times over the years since 1950, with the latest version signed in 1998. The U.S. government arrangement with Canada is unique and based upon the integrated North American defense concept.

Appendix 4
Alternative Cases

This section is classified.

Appendix 5
Assessing Strategic Risks of Scenarios: Protocols and Results

Appendix 5
Risks of Scenarios: Perspectives

This appendix will examine various perspectives on the strategic risks of potential scenarios that could disrupt the supply of strategic materials. They are: (1) Expert elicitation of future scenarios, (2) Frequency of historical scenarios.

Expert Elicitation of Future Scenarios: What are the significant risks to the security environment during the ensuing decade?

The Department of Defense (DoD) conducted a complementary, overarching assessment focused on broader strategic risks to U.S. national interests. This exercise consisted principally of structured interviews with senior retired and currently serving national security professionals, both military and civilian. Participants provided risk scores for future scenarios and categories of operations, and in doing so, offered quantitative estimates of both the probabilities and consequences associated with those scenarios and operations. In addition to the quantitative estimates for consequences (expressed as negative political, military, and economic utilities in each respondent's value system), respondents were asked to defend their estimates by providing supporting rationale.

This strategic exercise provides a range of potential conflict scenarios, along with the subject matter expert (SME)-estimated probabilities and consequences of these scenarios. The exercise provided estimated probabilities for the Base Case scenarios used in this report. Those probabilities are shown in Table A5.1 (with Base Case scenario probabilities listed as "Future #1" and "Future #2").[35]

Table A5.1. Selected Scenario Probabilities

	Probability		
	Max	Mean	Min
Future #1	6 percent	1.0 percent	0 percent
Future #2	1 percent	0.2 percent	0 percent

[35] Association of specific scenarios with the Base Case is classified and can be found in Appendix 2g of this report.

Exercise Method

The framework used was drawn from the Integrated Risk Assessment and Management Model (IRAMM),[36] which the Institute for Defense Analyses (IDA) developed in 2004 and 2005 to support an expert elicitation exercise involving senior military and civilian leaders in the DoD. This framework consisted of one-on-one, not-for-attribution interviews with senior leaders that lasted approximately 1.5 hours on average. Participants were asked to identify the strategic risk to the United States that they perceived in the decade from 2014 to 2024, based on their expectations for the performance of the currently-programmed U.S. military force structure.

The exercise was designed in the following way. First, four[37] challenge areas (CAs) were defined[38] that together cover a nearly-full range of potential conflict operations conducted by the U.S. military. The CAs and their definitions used in this exercise are shown in Figure A5.1.

Challenge Areas	Definitions
Major Combat	Operations conducted against a state or non-state actor that possesses significant military capability. This area should account for risk related to the use of WMD during the course of major combat. *e.g., China, North Korea, Iran, Libya*
Irregular Warfare	Stability operations, counterinsurgency, peacekeeping, or counterterrorism operations involving significant participation of U.S. forces in combat or prospective combat. *e.g., Iraq, Afghanistan, Syria, Bosnia, Somalia*
Homeland Defense (WMD & Cyber)	Protection of U.S. sovereignty, territory, population, and critical infrastructure against external threats. This area should delineate among risks from WMD, cyber attack, and all other forms of external attack (except those directly related to Major Combat). *e.g., 9/11, missile attack, WMD attack, cyber attack, other terrorist attack*

A5.1. Challenge Areas

[36] The name IRAMM was adopted in 2009. Before this, the framework described here was known as ICCARM (Integrated Cross-Capability Assessment and Risk Management). See IDA P-4470, IDA's Integrated Risk Assessment and Management Model, June 2009.
[37] WMD and Cyber were considered as separate challenge areas; results of these two challenge areas were compiled under the heading of Homeland Defense.
[38] The Challenge Areas were derived from the Quadrennial Defense Review 2014.

Respondents were asked to estimate risk for each of the three CAs based on their own identification of one or more scenarios in each of the CAs. For each scenario that the respondents identified, they were asked to estimate: 1) the likelihood that the scenario occurs in the next 10 years; and 2) the consequences of the scenario given that it occurs using the IRAMM consequence scale. These two parameters were then generally combined by multiplication, thus generating a risk score. This risk score is interpreted as the scenario's contribution to the "expected value of losses" over the ten year period.

Results

There was not a majority of respondents that ranked any one challenge area as the riskiest for the coming decade. Thirty-eight percent (6/16) rated WMD as the riskiest challenge area. Two CAs – Major Combat Operations (MCOs) and Cyber --were each ranked riskiest by 19 percent (3/16) of respondents. One respondent considered IW to be the riskiest CA and three respondents scored multiple CAs (one Cyber & IW, one IW & WMD and the other IW, MCO & WMD) as the riskiest. One respondent did not rank all four CAs. Since the risk of a scenario is calculated as the product of the probability of its occurrence and its consequences, there are multiple ways for a scenario to score as high risk. This is illustrated by the three CAs (WMD, MCO, and Cyber) that were most frequently rated as the riskiest by the respondents.

Respondents generally considered the likelihood of a WMD event in the homeland to be low (the median estimate of the probability of a nuclear attack was 4 percent); the consequences of such an event, however, were frequently deemed to be extremely detrimental to U.S. vital national interests. Many respondents had a similar view of cyber-attacks. Although cyber-attacks occur every day, most respondents deemed a significantly consequential cyber-attack to be unlikely. The respondents who ranked the Cyber CA as the riskiest, however, described potential cyber-attacks on the financial system or the electric grid as extremely harmful to U.S vital national interests. On the other hand, major combat was viewed as relatively more likely than WMD or Cyber scenarios (the median estimate of the probability that the U.S. would be involved in major combat in the coming decade was 32 percent). Many of the MCO scenarios proposed by respondents, however, were not deemed as consequential as a WMD attack or a significant cyber-attack.

Pros and Cons of Expert Predictions

The probabilities of future scenarios (including the base case scenarios) estimated in this exercise were based on the experts' judgment on the likelihood of the scenario in question. As such, these estimates vary from respondent to respondent and reflect their experiences and possibly their biases. Thus, they are not necessarily solely based on the frequency of similar scenarios in the past. However, the strength of using experts to estimate the probabilities of future events is that it allows for the fact that the past does simply “repeat itself”. The world changes and experts can and do stay abreast of those changes.

Frequency of Historical Scenarios: What is the historical frequency of scenarios that disrupt the supply of strategic materials?

Between 1914 and 2014, the U.S. was involved in four overseas military scenarios in which it experienced significant material supply disruptions of strategic and critical materials.[39] Strictly looking at these four events, the U.S. was engaged in conflicts for approximately twelve years as shown in Table A5.2. Those materials that the U.S. experienced supply disruptions included: synthetic sapphire (jewel bearings), tungsten, natural rubber, chromium and manganese. See Table A5.2 for a summary of the findings.

If one were to take into consideration these past events that led to supply disruptions, and ultimately material shortages faced by the U.S. over the past 100 years since 1914, one might arrive at a historical scenario frequency of 0.12 per year.

Table A5.2. Summary of Historical Scenarios Causing Supply Disruptions

Overseas Military Conflicts (1914-2014)	Conflict Years	Number of Years of U.S. Involvement	Materials in which U.S. Experienced Supply Disruptions	Countries Disrupting Supplies
1. World War I	1914-1918	2	Synthetic sapphire (jewel bearings) and tungsten	Germany
2. World War II	1939-1945	5	Synthetic sapphire (jewel bearings), tungsten and natural rubber	Germany and Japan
3. Berlin Blockade	1948-1949	1	Chromium and manganese	Soviet Union
4. Korean War	1950-1953	4	Chromium and manganese	Soviet Union

[39] Strategic and Critical Materials are “materials that would be needed to supply the military, industrial, and essential civilian needs of the United States during a national emergency, and are not found or produced in the United States in sufficient quantities to meet such need" (see 50 U.S.C. 98 et seq.).

Overseas Military Conflicts (1914-2014)

In the span of 100 years, a time in which the U.S. was acting as a major world power, there were four scenarios that resulted in material supply disruptions. The scenarios were: (1) World War I - 1914-18, (2) World War II - 1941-45, (3) Berlin Blockade - 1948-49, and (4) the Korean War - 1950-53.

World War I (WW I) lasted four years, however, the U.S. entered the War in 1917.[40] For two years, the enemy (i.e., Germany) cut off the U.S. supply of synthetic sapphire (one type of jewel bearing) from Switzerland, where most of the world's jewel bearings used in commercial and military products were produced.[41] In addition, Germany had procured on the open market virtually the entire world supply of low-grade tungsten ore, which left the U.S. and other foreign countries with shortages of the material.[42] Tungsten was established as a strategic military item in the munitions build-up period prior to WW I.[43]

WW II lasted six years; however, the U.S. did not enter into the War until 1941. Once again, but this time for five years, Germany cut off the U.S. supply of synthetic sapphire from Switzerland, where most of the world's jewel bearings were still being produced.[44] Also, with the outbreak of the war in the Pacific, and with Japan moving into Southeast Asia, the worst-case scenario came to pass: the United States was cut off from its principal source of natural rubber. These developments placed rubber near the top of the list of America's strategic and critical materials.[45] In addition, while there was a stockpile of sorts established in WW I, it was not sufficient to meet the needs of WW II.[46] Germany's military requirement for tungsten was very high, and they continued to buy virtually the entire world supply of low-grade tungsten ore which disrupted material supplies to the U.S.[47] During the Berlin Blockade, the conflict with the Soviets was not a direct, kinetic military confrontation but was treated as economic warfare. When the Soviet Union blockaded Berlin in 1948, cutting the city's land links with the West, the United States clamped down on exports of industrial goods to the Soviet Union. Among

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[40] Congressional Research Services, "Instances of Use of United States Armed Forces Abroad, 1798-2009," Richard F. Grimmett Specialist in International Security January 27, 2010.9.

[41] D. Sean Barnett, Barbara A. Bicksler, Theophilos C. Gemelas, Kenneth Kessel, (U) National Security Requirements for Jewel Bearings, IDA Paper P-2880, (Alexandria VA: Institute for Defense Analyses (IDA), April 1994) SECRET. I-3.

[42] Mildred Gwin Andrews, Tungsten: The Story of an Indispensable Metal, The Tungsten Institute (Washington D.C.) 1955. 9-11.

[43] Ibid. 11.

[44] D. Sean Barnett, Barbara A. Bicksler, Theophilos C. Gemelas, Kenneth Kessel, (U) National Security Requirements for Jewel Bearings, IDA Paper P-2880, (Alexandria VA: Institute for Defense Analyses (IDA), April 1994) SECRET. I-3.

[45] Paul A. C. Koistinen, "Arsenal of World War II: The Political Economy of American Warfare, 1940-1945". 2004 University Press of Kansas.148.

[46] Michael T. England, Captain, USAF, "U.S. Industrial Mobilization 1918-1988: An Historical Analysis." Air Force Institute of Technology Wright-Patterson AFB OH 45433-6583.200.

[47] Mildred Gwin Andrews, Tungsten: The Story of an Indispensable Metal, The Tungsten Institute (Washington D.C.) 1955. 9-11.

the goods embargoed were machinery, tools, trucks, and scientific instruments. In retaliation, the Soviet Union cut off shipments to the United States of raw materials critically needed by U.S. industry, mainly manganese, and chromium.[48] U.S. steel industry experts projected that roughly 1.4 million long tons of manganese would not be coming from the Soviet Union.[49]

In the Korean War, the Soviet Union was largely self-sufficient in mineral resources. The U.S. was not in direct military conflict with the Russians, but economic warfare had begun. U.S. concern over the availability of the strategic minerals of chromium, cobalt, manganese and platinum was increased by the realization that the Soviet Union was a major foreign source for U.S. demands of chromium and manganese. The Soviet Union halted exports of both manganese and chromium during the Korean War.[50]

Other Military Operations

From 1914 to the 1930s, U.S. military forces engaged in numerous interventions, primarily in China and South and Central America. Most of these were conducted by the Navy and Marine Corps. They usually involved small force operations and lasted for a few days or weeks. In a few instances, such as operations in Haiti, the operation lasted for several years. In these minor contingencies, shortages of equipment and consumables may have existed due to meager budgets for procuring additional material and supply chain problems, but none resulted in any disruptions of supplies of materials. In addition, the other conflicts the U.S. has been involved in, like the Vietnam War, the Gulf War, and Iraq and Afghanistan, along with other smaller, shorter conflicts, did not disrupt the supplies of strategic materials for the U.S.

Pros and Cons of Historical Projections

Historical data provides one way to estimate the probability of future scenarios that result in the disruptions of strategic materials. It may also be used to identify trends or patterns that might be able to provide insights about plausible future scenarios leading to strategic materials supply disruptions. However, as technology changes and substitution of materials evolve, world markets for these materials may get smaller and historical data may not provide a true picture of the underlying causes of strategic material supply disruptions. In addition, if the historical data is not available or is limited, then estimating frequency-based probabilities of supply disruption events may be misleading or infeasible.

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[48] Strategic Materials: Technologies to Reduce U.S. Import Vulnerability, (Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-ITE-248), May 1985.97.

[49] U.S. News & World Report, "Soviet embargos of manganese and chromium," December 16, 1949.26.

[50] Kent Hughes Butts, Strategic Minerals in the New World Orders, Strategic Studies Institute, U.S. Army War College, Carlisle Barracks, PA, November 30,1993.13.

Appendix 6
Materials Exhibits

6a. Nonproprietary Versions

Aluminum Fluoride

Description	Aluminum fluoride (AlF_3) is an inorganic, solid fluoride compound.	
Applications	Aluminum fluoride is an essential additive in the production of aluminum. It is used to lower the melting point of electrolytes in the smelting process that converts alumina to aluminum. Given today's technologies, it is impossible to make aluminum without AlF_3. Aluminum is a widely used material, both in industry and the military.	
Impact during a National Emergency	Imported aluminum could partially compensate for lost domestic aluminum production. Production of aluminum occurs in many countries, although China (33 percent) and Russia (10 percent) are the two largest producers.	
Shortfall	**Possible**	Work is currently under way to evaluate and quantify a potential shortfall.
Supply Risk	**Complete Foreign Reliance, Foreign Dominator**	The United States produces no AlF_3. China produces roughly 50 percent of world supply. Russia is the second largest producer at 10 percent. Smaller producers include Canada, Italy, and Mexico.
Recommended Action	Continue monitoring efforts.	

Supply Chain

The supply chain usually begins with acid-grade fluorspar. China (55 percent) and Mexico (20 percent) are the primary producers of acid-grade fluorspar. The United States produces no acid-grade fluorspar, and imports come primarily from Mexico. Acid-grade fluorspar reacts with sulfuric acid to produce hydrofluoric acid (HF). Hydrofluoric acid is produced in the United States by two large chemical companies. Next, alumina is treated with HF at elevated temperatures in a fluidized bed reactor. The result is AlF_3.

An alternate AlF_3 production method uses fluorosilicic acid (FSA) as the feedstock in place of HF. FSA is derived as a by-product from phosphate manufacture. This production method accounts for somewhat less than 20 percent of worldwide AlF_3 production.

Aluminum Oxide, Fused Crude

Description	Compound of aluminum and oxygen, Al_2O_3. Also known as alundum. Formed by fusing calcined bauxite in an electric arc furnace. Has high melting point and abrasive properties.	
Applications	Abrasive/milling products, clay building materials, refractories manufacturing, soaps, and cleaners	
Impact during a National Emergency	**Defense**	Moderate. Alternative materials, with poorer performance characteristics, could be used for many applications.
	Essential Civilian	Moderate. Alternative materials could be used for most applications.
Shortfall	**Yes**	A net shortfall of 18,268 short ton (ST)
Supply Risk	**Complete Foreign Reliance**	The United States no longer has any crude aluminum oxide production; 90 percent of imports come from China and Venezuela.
Recommended Actions	Purchase up to 18,268 ST for the NDS Program, with a projected cost of up to $9.5 million.	

Supply Chain

Bauxite is chiefly composed of aluminum oxide and aluminum hydroxide. The United States is 100 percent reliant on imports for its bauxite needs. When this mineral is fused in an electric arc furnace, brown fused alumina (BFA) and white fused alumina (WFA) can be produced. The United States has no crude aluminum oxide production. Production of high-purity aluminum oxide by two companies in the United States and Canada is limited. If these companies were to discontinue processing the material to high-purity grade, they could produce enough crude to cover a portion of the crude shortfall. Currently, the United States is 100 percent reliant on imports of crude fused aluminum oxide, which come predominantly from China (76 percent) and Venezuela (14 percent). The U.S. demand for fused crude aluminum oxide, as well as other manufactured abrasives such as silicon carbide, is largely influenced by the manufacturing industry. Key users include the aerospace, automotive, furniture, housing and steel industries. Specific applications include anti-slip additives, bonded abrasives, buffing/polishing compounds, coated abrasives (such as sandpaper), dry or wet blasting media, and tumbling media. Up to 30 percent of fused aluminum oxide may be recycled. Washington Mills has invested in a closed-loop manufacturing process for abrasives, in which it collects spent aluminum oxide grain and recycles it back into usable material. It should be noted that in most abrasive applications, fused crude aluminum oxide and abrasive-grade silicon carbide can be used interchangeably. Garnet, emery, and other metallic abrasives can also be substituted in various applications.

Ammonium Perchlorate

Description	Ammonium perchlorate (AP) is an acid salt, NH_4ClO_4. It is a powerful oxidizer when its particle size is greater than 15 microns, while smaller particles of AP are explosive.	
Applications	Ammonium perchlorate is predominately used in composite solid propellants for solid rocket motors (SRM) and boosters such as Aircraft "ejection seats" composite SRM (propellant oxidizer) and missiles.	
Impact during a National Emergency	**Defense**	Grade 1 AP is required for defense and aerospace propellants and has no good substitute.
Shortfall	**Possible**	Insufficient data available for modeling through the NDS Program stockpile sizing module.
Supply Risks	**Single Domestic Producer**	All AP manufactured in North America comes from one American company.
Recommended Action	Continue close monitoring and collaboration within the Department of Defense (DoD).	

Antimony

Description	Antimony (Sb) is a silvery-gray metal commonly alloyed with lead and tin to improve the alloy's physical properties.	
Applications	Lead hardener in ammunition, anti-friction alloys, and lead-acid batteries; alloyed with tin in certain lead-free solder; doping material in certain semiconductors. Antimony trioxide is an additive in textiles and plastics as a flame retardant.	
Impact during a National Emergency	**Defense**	Antimony metal is vital to manufacturing most lead-acid batteries utilized by the military. Indium antimonide semiconductors are used in FLIR vision systems and infrared homing missiles. Antimony trisulfide is used in fuses, small arms ammunition, mortar rounds, and artillery projectiles.
	Essential Civilian	Antimony in flame resistant textiles and plastics may be difficult to substitute.
Shortfall	**Yes**	A net shortfall of 13,118 short tons.
Supply Risk	**Foreign Reliance**	Single domestic primary producer. The United States is heavily reliant on foreign sources of antimony. Greater than half is imported from China, with Mexico being the second largest domestic supplier. Domestic production is primarily from recycling, but that provides only a portion of domestic consumption (~15 percent).
Recommended Action	The NDS Program requests legislative authority for the purchase of 13,094 short tons of antimony metal.	

Supply Chain

Antimony is a silvery-gray, brittle semi-metal that rarely occurs in nature as a native element; rather, it is usually found in minerals, primarily stibnite (SbS3). Antimony is rarely used as a pure metal, but it can be alloyed with lead to strengthen and harden it. Also, it can be formed into antimony trioxide (SbO3), and then added to textiles as a flame retardant. Antimony is relatively abundant in the earth's crust and is extracted as a principal product or a by-product of smelting of base-metal ores. Nearly all antimony is extracted in China. The U.S. resources of antimony are primarily in Alaska, Idaho, Montana, and Nevada.

The United States is heavily reliant on the importation of antimony (e.g., concentrate and ore, metal, oxide, and other compounds). Greater than half is imported from China, with Mexico being the second largest supplier. Domestic production is primarily from recycled lead-acid batteries, but recycling provides only a minor portion of total domestic consumption (~15 percent). Small quantities of antimony have been mined domestically as recently as 2007. None of the domestically recycled antimony can be used in the production of semiconductor materials. Domestically, antimony ore and concentrate can be processed into pure metal, oxide, and other compounds required for military applications.

Antimony can be substituted in most applications with other metals and compounds. Combinations of cadmium, calcium, copper, selenium, strontium, sulfur, and tin are substitutes for hardening lead for ammunition. Selected organic compounds and hydrated aluminum oxide are accepted substitutes for flame retardants. Lithium-ion batteries and antimony free lead-acid batteries can be substitutes for standard lead-acid batteries. Only a minor quantity of highly purified antimony (5N) is required for doping silicon wafers for semiconductors.

Estimated Demand

The consumption of antimony trioxide is expected to increase over the next several years. Antimony trioxide is utilized as a frame retardant in polyethylene terephthalate (PET) and synthetic textiles. Additionally, antimony trioxide and antimony pentasulfide are used to vulcanize rubber improving heat resistance. As third world countries and developing nations implement stricter fire regulations, the demand for antimony trioxide will increase.

The estimated demand for antimony metal is expected to remain flat or slightly increase. Antimony metal is primarily consumed in lead-acid automotive batteries, solder, and bearing materials. The demand for automobiles globally is increasing driven by Asian markets. Antimony is used in certain lead-free solders, demand is expected to remain flat; antimony is only used in a minority of solders and always at a low percent. Consumption of lead-antimony bearing materials is decreasing due to environmental concerns.

Supply Forecast

The 2014 USGS – Mineral Commodity Summary estimates global mining production decreased in 2013 from 2012. China accounts for 80 percent of all production, but due to the Chinese Government designating antimony a protected and strategic mineral all mine production of antimony is controlled. Production at multiple mine sites in Mexico is being significantly ramped up by expanding historical mines, mills, and smelters. Domestic secondary production is expected to remain flat..

Beryl Ore

Description	Beryl Ore includes beryl and bertrandite. These two main minerals are found in commercial beryllium ore used for beryllium production.	
Applications	Beryllium (Be) is an important material needed for military and space applications. Please see Beryllium Metal in the Proprietary section of this appendix.	
Impact during a National Emergency	**Defense**	Beryllium metal and alloy products have a critical function in many defense platforms and cannot be substituted by other materials.
	Essential Civilian	Limited
Shortfall	**No**	Per 2015 NDS Program report
Supply Risk	**Single Domestic Producer**	The transformation from beryl or bertrandite to beryllium hydroxide is taking place in only one domestic facility.
Recommended Action	Continue monitoring efforts.	

Supply Chain

The United States is the largest producer, processor and consumer of beryllium in the world. Although there is only one producer, it is a fully integrated beryllium company. The company also has the largest reserves of beryllium ore as bertrandite (estimated 65 percent of the world reserves) and provides as much as 85 percent of the world beryllium production. Beryl ore is imported from countries such as Brazil, Nigeria, South Africa and Mozambique, but the production in these deposits is sporadic because the veins of beryl are randomly distributed within the deposit and usually not very large.

Estimated Demand

The mine production for beryllium ores (based on beryllium content) has been historically ranging between ~ 200 and ~ 300 metric tons in the years following the end of the Cold War, with the U.S. being the largest producer (~ 80-85 percent). This production appears to have been sufficient to produce the beryllium needed globally.

Supply Forecast

Because of the small size of the beryllium market, little changes if any are anticipated. The predominant and established position of the market dominator will not change. A few companies exist in Russia, Kazakhstan and China that are able to provide beryllium products for the Asian market.

Bismuth

Description	Bismuth (Bi) is a brittle metal that is generally recovered as a by-product of other metal processing (lead, tin or tungsten). It has a high electrical resistance, lower thermal conductivity, and is the most diamagnetic of all the metals.	
Applications	Bismuth is a major component for various alloys and compounds, used in pharmaceuticals applications (e.g., over-the-counter stomach remedies), solders, ammunition, fireworks, cosmetics and plastics. It may be used as a successful substitute for lead in certain applications.	
Impact during a National Emergency	**Defense**	Substitution may be challenging in thermoelectric devices and some metal alloys used in defense. Bismuth-based alloys are used in machining. (e.g., work holding of turbine blade during machining).
	Essential Civilian	Often used as a nontoxic substitute to lead in brass, recyclable in some applications, and as an additive to enhance metallurgical quality (e.g., lead-free glasses, pigments, shot, and solder).
Shortfall	**No**	Per 2015 NDS Program study
Supply Risk	**Foreign Reliance**	The United States does not mine bismuth but does recycle it. China dominates the global supply. Import reliance is listed in descending order: China, Belgium, United Kingdom, and others.
Current Action	The NDS Program does not contain bismuth.	
Recommended Action	Continue monitoring efforts.	

Supply Chain

The United States is highly reliant on international bismuth production (91 percent import dependency). In 2013, the United States sourced most of its bismuth imports from China (55 percent) and Belgium (37 percent). Domestic primary production of bismuth ceased in 1997, and the last stocks of bismuth in the NDS Program were sold that same year.

Bismuth is usually produced as a by-product from lead, tin, and copper mining. Bismuth is primarily produced by China, which accounts for approximately 86 percent of world mine production and 75 percent of world reserves. In China, it is primarily a by-product of tungsten ore processing. Major bismuth producers are located in China, Mexico, and Vietnam.

Estimated Demand

In general, U.S. apparent consumption declined in 2009 to 2013 (-9 percent in 2012–2013 and -15 percent in 2011–2012). Consumption did increase in 2010–2011; however, this may be an outlier due to the economic recovery. U.S. consumption is driven by pharmaceutical applications, lead-free solder, and specialty alloys (fire detection systems, free machining steels, semiconductors.) The United States Geological Survey (USGS) estimated 2013 U.S. bismuth consumption to be 900 metric tons. U.S. apparent consumption has generally trended downward since 2005.

Worldwide demand may increase due to the European Union's REACH Regulation and Restriction of Hazardous Substances Directive and the United States' Reduction of Lead in Drinking Water Act. At this time there is only anecdotal evidence regarding the economic impact of these laws.

Supply Forecast

The worldwide supply of bismuth has generally declined since 2008. The 5 year forecast based on the latest available USGS data implies continued declines. This forecast may be revised due to newly available data from 2014. Bismuth supplies in 2014 are slightly tighter than in earlier years.

China monitors bismuth exports; however, there is no evidence of a supply quota on this material. There is also no indication that China may embark on constricting bismuth production. Preliminary evidence suggests defense demand may be fulfilled by multiple mines and refineries in Canada, Mexico, and Vietnam in case Chinese production is restricted. In addition, there is a small quantity of domestic secondary production of bismuth from new and old alloy scraps. According to the 2014 USGS Mineral Commodity Summary, domestic recycling accounts for 10 percent of domestic consumption or 80 tons. U.S. recycled bismuth supply growth is flat.

Boron

Description	Boron (B) is a metalloid found naturally in the form of boric oxide (B_2O_3).	
Applications	Abrasives, ceramics, glass, detergent, fertilizer, magnets, body armor, armor plates, nuclear reactor control rods, fire retardants.	
Impact during a National Emergency	**Defense**	Heavier body armor solutions could be substituted.
	Essential Civilian	None; other materials could be substituted.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risk	**Limited**	Domestic supply is adequate. Multiple domestic producers.
Recommended Action	Continue monitoring efforts.	

Supply Chain

The majority of boron products consumed in 2012 by the United States were manufactured domestically. Four main borates make up the majority (90 percent) of worldwide consumption: colemanite, kernite, tincal and ulexite.

Although borates have a plethora of uses, the glass and ceramics sector consumed about 80 percent of boron products in the United States. The remainder was used for abrasives, cleaning products, agriculture, and in the production of semiconductors. Defense applications of boron include aircraft engine components, ballistic personal and vehicle armor, permanent magnets, and rocket fuels. In ceramics, borates are used as fluxing agents and, in the form of boron carbide, as lightweight ballistic armor. In glass production, it is used to reduce thermal expansion, improve strength, chemical resistance, and durability and to provide resistance against vibration, high temperature, and thermal shock. The largest single use (~45 percent of world consumption) was insulation and textile fiberglass. As the international market demand in the insulation industry increases, so does the need for boric acid. Chinese producers are unable to compete in high-quality borates. Borates were also used in various materials for their flame-retardant properties. Boron is used in nuclear reactors to shield radiation and control reactivity and in emergency shutdown systems. The capability and use of recycling are insignificant. Sodium percarbonate and chlorine can be substituted in detergents where boron is used. With regard to insulation, cellulose, foam, and mineral wools can be substituted.

Boron Carbide

<table>
<tr><td>Description</td><td colspan="2">Ceramic-grade boron carbide (B_4C) is a synthetic compound made from synthesizing boron and carbon into a B_4C crude material that is reduced and refined into fine powders for manufacturing ceramics. B_4C has a high melting point, thermal stability, abrasive resistance, hardness, and absorbs neutron radiation. B_4C materials assessed for this report are limited primarily to those qualified for DoD body armor requirements and other DoD weapon system uses.</td></tr>
<tr><td>Applications</td><td colspan="2">B_4C more generally is used mostly in commercial abrasives and refractories, in addition to small niche applications in technical ceramics, including nuclear shielding, wear parts, electronics manufacturing, and ballistic protection. B_4C crude and powder demand assessed for this report include only those used for DoD ballistic protection including body armor and other DoD defense systems.</td></tr>
<tr><td rowspan="2">Impact during a National Emergency</td><td>Defense</td><td>Significant. A U.S. defense shortfall for B_4C crude is estimated for all 4 years of the 2015 NDS Program Base Case. There are currently no readily available (i.e., qualified) substitutes for B_4C crude in many DoD armor applications.</td></tr>
<tr><td>Essential Civilian</td><td>Unknown. Base Case civilian B_4C crude and powder demands were not evaluated for the 2015 NDS Program RR, and as such civilian shortfalls were not assessed.</td></tr>
<tr><td>Shortfalls</td><td>Yes</td><td>Amount withheld</td></tr>
<tr><td>Supply Risk</td><td>Significant Foreign Dependence</td><td>While B_4C crude and powders of all types are produced in the United States and multiple countries including China, Germany, India, and the Ukraine, specific crude and powder materials for DoD armor requirements are a lot more limited.</td></tr>
<tr><td>Current Actions</td><td colspan="2">In addition to in-depth industrial base and supply chain assessments of B_4C crude and powders by the Defense Logistics Agency Strategic Materials for possible stockpiling and other risk mitigation purposes, The Defense Logistics Agency Strategic Materials is collaborating with multiple DoD offices and agencies on other assessments and mitigation options</td></tr>
<tr><td>Recommended Action</td><td colspan="2">Acquire B_4C crude for DoD stockpiling purposes. Amount and projected cost withheld. Continue coordinating with DoD components on other risk mitigation options (e.g., possible qualification of alternative suppliers).</td></tr>
</table>

Borosilicate Floated Glass

Description	Borosilicate glass is manufactured using a float process, weighs less than soda lime glass, and is resistant to degradation from many industrial chemicals and higher temperatures.	
Applications	Defense uses include opaque ballistic armor and transparent armor window systems. Lightweight alternative to conventional vehicle armor solutions. Commercial uses include home appliances, lighting industry, and chemical industry.	
Impact during a National Emergency	**Defense**	U.S. military ground vehicles utilize a proprietary borosilicate float glass in Explosively Formed Penetrator (EFP) armor kits used against heavy ballistics threats, and in transparent armor window systems. Vehicle armor shortages were seen during previous U.S. conflicts, and DoD users could turn to armor solutions with higher weight or lower ballistic protection levels.
	Essential Civilian	Limited alternative products and materials are available.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risks	**Foreign Reliance**	Single and foreign supplier (Germany). There are no other DoD-qualified materials with the same weight, performance, and transparency characteristics. Other armor materials with performance and weight trade-offs are available domestically.
Recommended Action	Continue monitoring efforts.	

Supply Chain

A German manufacturer is the sole manufacturer of borosilicate float glass. Their product can be produced to various thicknesses and sheet sizes. The thicker products (3/4 in. and 1 in.) are used as ballistic armor substrates on ground vehicle explosively formed penetrator (EFP) kits. The product is also used on some ground vehicle transparent armor window systems. There are several alternative materials for transparent armor that are available domestically but have performance and weight trade-offs.

1,2,4-Butanetriol, Precursor to 1,2,4-Butanetriol Trinitrate

Description	1,2,4-butanetriol (BT) is a synthetic organic compound that can be synthesized by multiple routes, but purification is essential for its use as a precursor to 1,2,4-butanetriol trinitrate (BTTN), a nitrated plasticizer. BTTN is an explosive, shock-sensitive liquid that is used as an additive to increase the burn rate of solid rocket propellants.	
Applications	High-purity BT is used as a propellant plasticizer in missile rocket motors. Lower-grade BT is used as a precursor in organic synthesis of pharmaceuticals.	
Impact during a National Emergency	**Defense**	BT is needed for producing BTTN. BTTN is used in defense applications where insensitive munitions, smokeless exhaust, and stability in storage are of great importance and substitution is therefore complicated.
	Essential Civilian	Lower-grade BT can be purchased from many commercial chemical companies in the United States.
Shortfall	**Possible**	Insufficient data available for modeling through the NDS Program sizing module.
Supply Risks	**Foreign Reliance Mitigated**	Previously, foreign reliance (on China) for high-purity BT, but a single U.S. supplier was recently qualified.
Recommended Actions	Continue close monitoring and collaboration within DoD.	

Carbon Fiber, Polyacrylonitrile-Based

Description	Polyacrylonitrile (PAN)–based carbon fibers serve as a continuous reinforcement material incorporated in advanced polymer matrix composites. Certain grades are widely used in U.S. military and aerospace applications. PAN-based carbon fibers are often classified as high strength (HS), high modulus (HM), intermediate modulus (IM), or standard grade (SG).	
Applications	Defense – high-performance carbon fibers are used in various critical defense and national security space (NSS) applications such as rocket motors, space launch vehicles, manned and unmanned military aircraft, and satellites. Civilian – Commercial aviation, sporting goods, and industrial products.	
Impact during a National Emergency	**Defense**	Carbon fiber composites are used on U.S. space programs and on military aircraft. They are critical for global precision; intelligence, surveillance, and reconnaissance (ISR); and sustained engagement capabilities.
	Essential Civilian	Modest. IM carbon fiber composites are heavily used in commercial aviation.
Shortfall	**Yes**	Amount withheld.
Supply Risk	**Foreign Reliance**	Please see Proprietary section.
Current Actions	Carbon fiber supply chains are under investigation by U.S. government space and missile communities. The Space Industrial Base Council (SIBC) Critical Technologies Working Group (CTWG) and the Defense Logistics Agency are evaluating mitigation options. Defense Logistics Agency Strategic Materials is seeking legislative authority to qualify alternative products and to establish a stockpile.	
Recommended Action	A three-pronged approach is recommended. First, collaborate with other agencies and with industry to establish new domestic production. Second, collaborate with other agencies and with industry on research and development support to help qualify a domestic source for the production of certain fibers. Third, stockpile those fibers for which prongs one and two are unlikely to be successful.	

Carbon Fiber, Pitch-based

Pitch-based carbon fibers are heavily used in aircraft brakes and space satellite structures. There are two major Japanese manufacturers of pitch-based carbon fiber and one U.S. manufacturer. Defense Logistics Agency Strategic Materials considers pitch-based carbon fibers to be important to defense and essential civilian applications. There is currently not enough data to fully assess the supply chain and the impact of a conflict scenario on the availability of this material. Defense Logistics Agency Strategic Materials will continue to monitor this material and gather data on the supply chain in order to make an assessment in the next report.

Carbon Fiber, Rayon-based Aerospace Grade

Description	Aerospace-grade rayon fiber has low thermal conductivity and high strength. This makes the material useful for heat shields and other applications.	
Applications	Space and missile applications, specifically in the throat, nose cap, and exit cone sections of solid rocket motors and the heat shields for re-entry vehicles.	
Impact during a National Emergency	**Defense**	Significant, as no qualified substitutes exist for certain applications. Finite quantities are available in government stockpiles, and some platforms have qualified foreign-produced rayon.
	Essential Civilian	Limited. Substitute materials are available for less stringent applications.
Shortfall	**Possible**	See Proprietary section.
Supply Risk	**Complete Foreign Reliance**	No domestic suppliers. See Proprietary section.
Current Actions	The Defense Logistics Agency Strategic Materials is conducting an in-depth supply chain investigation. The space and missile communities, including NASA, Navy, and MDA, participate in a CTWG that is monitoring this issue. The goal of the supply chain analysis is to identify mitigation actions for supply issues, including potential substitution materials.	
Recommended Action	Continue supply chain analysis.	

Chlorosulfonated Polyethylene (Synthetic Rubber)

<table>
<tr><td>Description</td><td colspan="2">Chlorosulfonated polyethylene (CSM) elastomers are olefin polymers that have been simultaneously chlorinated and chlorosulfonated to yield a family of curable polymers, varying from soft and elastomeric to hard and plastic, containing pendant chlorine and sulfonyl chloride groups. During the early 1940s, as part of the war effort, DuPont initialized the development of CSM. DuPont was attempting to create a vulcanizable elastomer with the electrical and chemical properties of polyethylene. Instead, chlorinated polyethylene (CPE) was created, but it was difficult to vulcanize with the limited peroxides available. In time, the process was modified, which allowed simultaneous chlorination and chlorosulfonation of polyethylene and therefore allowed curing to occur with sulfur-bearing curatives.</td></tr>
<tr><td>Applications</td><td colspan="2">Automotive components, tires, belts, hoses, industrial products, construction (roofing and geomembranes), wire and cable, molded goods, and coatings.</td></tr>
<tr><td rowspan="2">Impact during a National Emergency</td><td>Defense</td><td>Required for cables, linings/coatings for tents, boats, and similar articles. Substitution and recycling are limited.</td></tr>
<tr><td>Essential Civilian</td><td>Automotive and industrial uses involve a combination of natural and synthetic rubber. Recycling is limited due to a loss of properties in the recycling process.</td></tr>
<tr><td>Shortfall</td><td>Yes</td><td>There is a net defense shortfall of 216 metric tons.</td></tr>
<tr><td>Supply Risk</td><td>Foreign Reliance</td><td>The United States imports from Japan and China. U.S. production ceased in 2008.</td></tr>
<tr><td>Recommended Action</td><td colspan="2">As a net shortfall material, CSM is recommended for further study and stockpiling.</td></tr>
</table>

Estimated Demand

Since 2008, world CSM demand has dramatically decreased, especially in the United States and Western European markets, and fell from 19,800 metric tons in 2008 to just 12,400 metric tons in 2011, at an average annual growth rate of -14 percent. Consumption in the United States fell from 11,000 metric tons in 2008 to 4,500 metric tons in 2011. One outcome of this was product substitution in the areas most affected, as well as a new supply of CSM from Asian sources. Production in Asia has increased during 2010–2012, which has led to a small rebound in the market, but not to its former level.

The United States, Western Europe, China, and Japan accounted for nearly 80 percent of world CSM consumption in 2011. CPEs have been adopted in many applications in a variety of industries, such as the construction sector (roofing membranes, pond and reservoir liners), automotive sector (hoses, tubing, and belts), industrial products sector (seals, belts, linings, printing rolls, and linings for tanks), wire and cable sector, and others (molded goods and articles, coatings and adhesives). The largest end use for CSM continues to be parts for the automotive sector, accounting for roughly 30 percent of the world market.

World consumption of CSM is expected to reach nearly 14,000 metric tons by 2017, growing at an average annual rate of 1.7 percent during 2011–2017. China is expected to show the largest average annual growth rate (4.3 percent) because of its expanding automotive, electrical, and industrial markets, followed by the rest of the world—mainly other parts of Asia (3.5 percent) and Japan (1.8 percent)—with negative growth in the United States and Western Europe. Markets for CSM have been shifting toward Asia.

Supply Forecast

In 2011, total world capacity for CSM was 15,000 metric tons, and production was estimated at 11,500 metric tons. Prior to the closure of DuPont's CSM unit in the United States in 2008 and the cessation of production worldwide in 2010, world production capacity for CSM was close to 40,000 metric tons. DuPont's actions created a major disturbance in the world CSM market. Japan and China are now the largest CSM suppliers in the world, with Japan being the largest exporter. As of 2011, the United States still leads in terms of world CSM consumption, with China close behind. It is expected that China will soon be the largest world consumer of CSM by 2016–2017.

Projected world capacity in 2017 should be adequate to meet projected consumption through 2017. World capacity is expected to grow by a few thousand metric tons, as China will be adding capacity during 2012–2015.

Chromium Metal

Description	Pure chromium metal (Cr), produced by electrolytic or aluminothermic processes, and further purified by vacuum degassing. Forms traded include cathode flakes, briquettes, and fine powders.	
Applications	High-purity chromium metal is used in nickel- or cobalt-based superalloys for corrosion resistance and material properties at high temperature. Lower-grade chromium metal used for final adjustment of steel alloy composition.	
Impact during a National Emergency	**Defense**	Superalloys used in turbine engines for jet aircraft, tanks, and marine applications.
	Essential Civilian	Superalloys used in commercial turbine engines for aircraft, marine, and land electric power generation applications.
Shortfall	**No**	Per 2015 NDS Program study.
Supply Risk	**Foreign Reliance**	Most electrolytic chromium metal is produced in Russia. Aluminothermic chromium metal is produced in China, France, Russia, and the United Kingdom.
Current and Recommended Action	National Defense Stockpile contains about 4,054 metric tons of chromium metal, plus larger amounts of ferrochromium. Continued study of stockpile for suitability in defense uses.	

Supply Chain

The chromium supply chain is dominated by chromite ore and ferrochromium used for stainless steel production. Chromium metal represents on the order of 2 percent of the overall chromium market. The main U.S. producer of electrolytic chromium metal ceased production in 2009. One company produces high-grade chromium chemicals, including oxide, and another prepares and sells chromium powder made from electrolytic chromium.

Electrolytic chromium metal is produced in Russia. Aluminothermic chromium metal is produced in France, Russia and the United Kingdom. Recently, a number of Chinese firms have become established chromium metal producers. The November 2013 USGS Mineral Industry Survey shows that China now produces almost a third of the overall chromium metal imported into the United States, and over half the unwrought powder.

A comprehensive review of the supply chain for high-purity chromium metal for superalloys was conducted by the National Research Council in 1995. At the time, the review found that the production capability exceeded demand. Since then, several firms have ceased production, and the world's production capability more nearly matches demand.

Estimated Demand

The November 2013 USGS Mineral Industry Survey for Chromium indicates that annualized imports of all forms of chromium metal in 2013 were on the order of 13,000 metric tons. It also shows consumption in superalloys as 5,600 metric tons, annualized. The 1995 National Research Council study estimated U.S. consumption of high-grade chromium metal as approximately 6,000 metric tons per year. This is consistent with the USGS 2013 data and indicates a consistent demand rate. Chromium chemicals are also used in a number of industries. Chromium oxide is a precursor to electrolytic chromium metal, and chromic acid is used by the chromium electroplating industry.

Supply Forecast

Chromium metal supplies from France and the United Kingdom are likely stable. Plants producing electrochemical and aluminothermic chromium in Russia are aging; some upgrades appear to be under way to ensure reliable operation. Production in China is likely growing. There appears to be an adequate source of supply today, but the U.S. superalloy industry relies upon imports from China, Russia, and Europe.

Cobalt

Description	Cobalt (Co) is a hard, ferromagnetic metal that retains its strength at high temperatures. It is supplied as cobalt metal and alloy products, cathode metal, metal powder, cobalt oxide and hydroxide, and other forms.	
Applications	Superalloys and other metal alloys, batteries, magnets, cemented carbides, pigments, catalysts, magnetic coatings.	
Impact during a National Emergency	**Defense**	Limited substitution is possible. Main defense uses are superalloys used in jet engines, Stellite alloys, nickel–metal hydride (NiMH) and lithium-ion batteries, samarium-cobalt and Alnico magnets.
	Essential Civilian	Limited substitution and recycling possible for civilian uses.
Shortfall	**No**	Per 2015 NDS Program study.
Supply Risk	**Foreign Reliance, Single Failure**	No U.S. mine production and only one domestic producer of recycled product. Foreign reliance is on Democratic Republic of Congo for mining and China for refining.
Current Action	National Defense Stockpile contains 301 metric tons of cobalt.	
Recommended Action	Recommend holding remaining inventory. Continue monitoring efforts.	

Supply Chain

Cobalt is generally produced as a by-product of copper, nickel, and other metals. The majority of cobalt, roughly half of global supply, is mined in the Democratic Republic of Congo (DRC). In addition, cobalt is also mined in Canada, China, Russia, Australia, Zambia, and several other countries. The only primary cobalt mine is in Morocco. China was the world's leading producer of refined cobalt, mostly using concentrates from DRC. Imports of refined cobalt by the United States were from China, Norway, Russia, and other countries. In 2013, about 24 percent of U.S. apparent consumption was met through the secondary market.

The one sole producer of cobalt metal powder in the United States separates cobalt from cemented carbide scrap. A number of downstream producers use cobalt in cemented carbides and various alloys, including a number of major turbine engine manufacturers. Increasing quantities of cobalt chemicals are being processed by producers of NiMH and lithium ion batteries.

Estimated Demand

Domestic apparent consumption has been relatively steady since the 1950s. The U.S. apparent consumption estimated by USGS for 2013 was 9,300 metric tons. Almost half the cobalt consumed in the United States is used in cobalt-based superalloys and as an alloying element in nickel-based superalloys. About 9 percent of that consumed is used in cemented carbides. Other metallic applications, including cobalt-based Stellite alloys, maraging steel alloys, and both samarium cobalt and Alnico magnets, account for 16 percent of demand. The remaining 27 percent is used in chemical applications such as pigments, catalysts, tire adhesives, and preparation of magnetic coatings. Batteries have become a major application for cobalt chemicals. The Cobalt Development Institute estimates that batteries may consume more than a quarter of the world's cobalt supply. Battery applications show the most significant possibilities for increased cobalt demand.

Supply Forecast

Cobalt and copper output in DRC may increase substantially in the near future, assuming political and economic stability continues in the eastern part of that country. With overall demand relatively stable, the cobalt market should be well supplied and prices are expected to fall. Chinese firms have been buying control of DRC mines to ensure supplies of raw material for cobalt refining. Construction of a cobalt mine in Idaho has been suspended based on poor prospects for profitability. Cobalt may be recovered at the Eagle copper and nickel mine under construction in Michigan. Growth in demand for the use of cobalt in batteries may offset increased potential for production.

Cyclotetramethylene-tetranitramine and Cyclotrimethylene-trinitramine

<table>
<tr><td>Description</td><td colspan="2">Cyclotetramethylene-tetranitramine (HMX) and cyclotrimethylene-trinitramine (RDX) are high explosives.</td></tr>
<tr><td>Applications</td><td colspan="2">Significant use by the military for aerial bombs, mines, and torpedoes as well as a variety of missiles. Also used in controlled demolitions and as perforators for the oil and gas industry.</td></tr>
<tr><td>Impact during a National Emergency</td><td>Defense</td><td>Potentially significant because HMX and RDX are used as ingredients in several different explosives. Nitrotriazolone (NTO) is a substitute for RDX, and triamino-trinitrobenzene (TATB) is a substitute for HMX. Both NTO and TATB are produced within the United States.</td></tr>
<tr><td>Shortfall</td><td colspan="2">Insufficient data available for modeling through the NDS Program sizing module.</td></tr>
<tr><td>Supply Risks</td><td>Single Domestic Producer</td><td>No imports but only one manufacturer that produces both these high explosives within the United States. The production of HMX and RDX requires strong nitric acid, which is also on the NDS Program Watch List because of supply issues.</td></tr>
<tr><td>Recommended Action</td><td colspan="2">Continue monitoring efforts.</td></tr>
</table>

Fluorspar

Description	Mineral containing calcium fluoride (CaF_2). Acid-grade fluorspar has greater than 97 percent CaF_2, while metallurgical grade contains <97 percent CaF_2.	
Applications	Acid-grade fluorspar is used to make hydrofluoric acid (HF). HF is used in refrigeration, foam blowing, fire suppression, insulation, uranium manufacture, and various other uses. Another key use is in the production of aluminum fluoride, a critical component in aluminum production. Metallurgical grade is mainly used as flux in steelmaking.	
Impact during a National Emergency	**Defense**	Supply expected to cover defense demand.
	Essential Civilian	Industry would draw from current inventories.
Shortfall	**Acid Grade**	No
	Metallurgical Grade	No
Supply Risks	**Foreign Reliance**	A single domestic mine site is under development. Large producers are Mexico and China. Smaller producers are South Africa, Mongolia, and Russia.
Previous Activity	Previously stockpiled by the NDS Program. The DoD authorized sale of entire stockpile in 1993, which was subsequently completed in 2006. There is currently no stockpile.	
Recommended Action	Continue monitoring efforts.	

Supply Chain

China and Mexico are the major suppliers of fluorspar, making up 65 percent and 17 percent of the market, respectively. Fluorspar is currently not produced in the United States, except for small amounts obtained as by-products of other processes. A new mine with an estimated 70,000+ metric ton capacity is under development in Livingston County, Kentucky, but it is uncertain whether it will eventually open. From 2008–2011, the United States imported fluorspar from Mexico (69 percent), China (20 percent), and South Africa (8 percent). Concerted programs exist in Mexico and South Africa to expand capacity in their current facilities. A planned expansion at the Las Cuevas Mine in Mexico plans to increase its capacity this year, however, the acid-grade fluorspar produced there contains high levels of arsenic, and only a single U.S. plant is capable of using it. The Vergnoeg Mine in South Africa has extensive capability to increase production, given significant funding ($20 million). Domestically, acid-grade fluorspar accounts for the substantial majority of fluorspar consumption. It is used mostly in hydrofluoric acid (HF) production. HF is a precursor to almost all fluorine compounds. Fluorspar is used to produce aluminum fluoride, an essential ingredient in aluminum production, and to produce sulfur hexafluoride (SF_6), which is used by the U.S. Air Force (USAF) and U.S. Navy (USN) in high-voltage electronics, aircraft radar systems, submarine sonar systems, and torpedo propulsion systems. Metspar, a form of fluorspar, is primarily used as flux in steel and aluminum production. However, aluminum smelting dross, borax, calcium chloride, iron oxides, manganese ore, or silica sand titanium dioxide can be used as substitutes for Metspar in this application. Yearly, approximately 3,000 metric tons of synthetic fluorspar is recycled from uranium enrichment, petroleum alkylation, and stainless steel pickling. By-product fluorosilicic acid has been used as a substitute in aluminum fluoride production and also has the potential to be used as a substitute in HF production.

Gallium

Description	Most primary gallium (Ga) is extracted as a by-product of the refining of bauxite into alumina. However, given the low concentrations and cost of extracting gallium, most alumina refiners do not capture it. The most common forms of gallium are gallium metal, gallium arsenide, and gallium nitride. Gallium antimonide is used for night vision and missile guidance.	
Applications	Integrated circuits, optoelectronics, laser diodes, light-emitting diodes, solar cells, radar missile defense, and infrared imaging.	
Impact during a National Emergency	**Defense**	Electronics, missile guidance
	Essential Civilian	Electronics
Shortfall	**No**	Per 2015 NDS Program Report.
Supply Risk	**Foreign Reliance**	The United States is 99 percent import reliant. Key import sources are Germany, United Kingdom, China, and Canada.
Current Actions	Gallium is an essential element for compound semiconductors used in many ground and space microwave transistor and integrated circuit applications. Gallium provides the high-efficiency, high-frequency, high-power, and low-noise properties critical for satellite communications. Microwave power transistors using gallium nitride (GaN) are becoming increasingly important because of the substantial reductions in weight in future satellites. This material is also used to manufacture solar cells for spacecraft power generation. Furthermore, the United States is currently 100 percent import dependent for its estimated consumption of 33.5 metric tons of annual primary gallium.	
Recommended Action	Prepare a supply-chain analysis in FY 2015.	

Estimated Demand

Global demand for gallium in 2012 was estimated to be 250 metric tons. The United States consumed approximately 34 metric tons consisting of 20.6 metric tons of primary gallium and 13.8 metric tons of secondary gallium. As mentioned above, imports of gallium and gallium arsenide (GaAs) supplied nearly all U.S. demand for gallium in 2012. Principal import sources were Germany (32 percent of all imports), United Kingdom (27 percent), China (15 percent), Canada (11 percent), and other countries (15 percent). Market conditions for GaAs improved in 2012 driven by strong growth in smartphones and other high-speed wireless applications. Meanwhile, due to its large power-handling and high-voltage capabilities, GaN has been gaining wider market acceptance in power electronics, commercial wireless infrastructure, and satellites.

Supply Forecast

Assuming gallium is present in bauxite at a concentration of 50 ppm, the United States has an estimated 15,000 metric tons of gallium resource. However, as most of the country's bauxite is not economical, the gallium contained therein is not recoverable. It is generally believed that the United States has gallium present in concentrations as high as 50 ppm in domestic zinc ores, which could serve as a substantial resource, but because of a lack of available ore, the United States produced no primary gallium in 2012. Imports supply approximately 99 percent of U.S. gallium consumption, of which Germany supplies 32 percent, while a small amount of gallium is recovered from GaAs.

According to USGS estimates, world primary gallium production was estimated to be 383 metric tons in 2012. China, Germany, and Kazakhstan were the leading producers, accounting for 91 percent of global production. Refined gallium production was estimated to be about 354 tons, which included primary gallium production and some possible scrap refining. China, Japan, the United Kingdom, and the United States were the principal producers of refined gallium. Gallium was recycled from new scrap in Canada, Germany, Japan, the United Kingdom, and the United States. World primary gallium capacity in 2012 was estimated to be 474 tons; refinery capacity, 270 tons; and recycling capacity, 198 tons.

Gallium Arsenide

Description	Gallium arsenide (GaAs) is a compound of the elements of gallium and arsenic and belongs in the class of III-V Group semiconductors. The electrical properties of GaAs are superior to those of silicon. For example, GaAs transistors are faster and more efficient than silicon-based integrated circuit chips, with electrons moving five times faster in GaAs. GaAs is also relatively insensitive to heat as compared to silicon because of its wider band gap, and GaAs devices emit less noise – a key characteristic in defense applications.	
Applications	Cell phones, light-emitting diodes (LEDs), integrated circuits, flat panel displays (FPDs), solar thin film photovoltaics (CIGS), magnets and liquid displays.	
Impact during a National Emergency	**Defense**	Critical for radar, short wave infrared tracking, night vision, satellite communications. Silicon and gallium nitride (GaN) are potential substitutes for GaAs, depending on qualification requirements of specific platforms.
	Essential Civilian	Consumer electronics
Shortfall	**No**	The United States is currently 100 percent import dependent for its estimated annual consumption of 33.5 metric tons of annual primary gallium.
Supply Risk	**Foreign Reliance**	Primary gallium
Current Action	Gallium is an essential element for compound semiconductors used in many ground and space microwave transistor and integrated circuit applications.	
Recommended Action	Further supply chain analysis should be undertaken in order to understand the supply chain for this semi-finished, processed material.	

Estimated Demand

Gallium arsenide is one of the most common forms of gallium used in semiconductor and solar applications. The electronics sector, particularly smartphones, LEDs, monolithic microwave integrated circuits (MMICs), FPDs, and wireless applications, are the main end-use drivers for GaAs.

GaAs substrates are coveted for their semiconducting and semi-insulating properties. Semiconducting substrates are used in optical devices (infrared emitting diodes, laser diodes, photo detectors, LEDs, etc.), while semi-insulating substrates are used in electronics [digital integrated circuits, field effect transistors, MMICs, and ultra- high frequency (UHF) wave devices] and photovoltaics. Gallium provides the high-efficiency, high-frequency, high-power, and low-noise properties critical for satellite communications. Microwave power transistors using GaN are becoming increasingly important because of the substantial reductions in weight in future satellites. This material is also used to manufacture solar cells for spacecraft power generation.

The United States is the world's third largest consumer of gallium behind Japan and China. While official statistics are not available, the USGS collects usage data for the United States by industry survey. Since participation is voluntary and response rates are less than 100 percent, USGS analysts estimate total gallium usage for the United States. U.S. demand for gallium totaled an estimated 34 metric tons in 2012, down slightly from 2011. Integrated circuits accounted for 68 percent of usage, while optoelectronics made up the balance. While the United States is nearly 100 percent import reliant on primary gallium, the country is home to several manufacturers of gallium-based electronics and optoelectronics, as well as hetero-junction bipolar transistor (HBT) wafers for wireless power amplifier (PA) circuits, as well as components used in radio frequency and microwave applications. While further research would be needed for specific requirements, it appears that the United States is well positioned in the middle and downstream tiers of the supply chain.

Growth in the demand for GaAs will be a function of the growth of its main end uses. Roskill, forecasts a cumulative average growth rate (CAGR) of between 30 percent and 50 percent per year for many of the end markets that utilize GaAs substrates. Worldwide *total* gallium (all gallium products) demand is forecast to reach approximately 350–400 metric tons by 2017, of which approximately half will be GaAs.

Supply Forecast

Estimates for the supply of virgin gallium is complicated by the fact that primary gallium is the by-product of alumina and zinc processing. Secondary production of gallium is a major source of material for producers of gallium compounds. However, supply data for recycled material are only estimates at best due to the paucity of data and the fact that a substantial portion of recycled gallium in Japan is captured in the liquid-phase epitaxy (LPE) "loop" (meaning gallium consumed in the LPE sector is recycled and reused in the LPE sector) and is therefore unavailable to the broader market. Despite these challenges, the USGS has estimated world primary gallium capacity in 2012 of 474 tons; refinery capacity, 270 tons; and recycling capacity, 198 tons.

Estimates for GaAs supply are even more difficult to ascertain because of a lack of published data stemming from company policies on production capabilities. Further research is required in this area.

While estimates of worldwide GaAs production are unknown, there is a wealth of information regarding the main producers and their manufacturing methods. There are approximately 33 producers of GaAs substrates operating in seven countries using various crystal growth methods and epitaxial layering techniques. Summary information on these suppliers can be found in Roskill (IBID, pages 64–74). There are nine U.S.-based GaAs manufacturers, of which eight operate facilities in the United States.

Germanium

Description	Germanium (Ge) is a metalloid that is supplied as a by-product of zinc mining. Germanium comes in a variety of forms including germanium oxides, germanium metal, and germanium powder.	
Applications	Fiber optics, infrared optics, polymerization catalysts, electronics, and solar cells. Key defense applications include missile guidance and solar cells for satellites.	
Impact during a National Emergency	**Defense**	High-purity germanium is manufactured into infrared (IR) lenses for most DoD night vision technology, thermal imaging systems, and IR tracking systems in combat vehicles. These applications are essential for tracking ground targets and heat-seeking missiles and conducting nighttime counterinsurgency operations. In addition, high-purity germanium substrates are utilized in the manufacture of solar cells that power defense and national security space satellites. These satellites are critical for reconnaissance, missile detection, and communication. Two areas of significant growth within the military are the use of unmanned aerial vehicles (UAVs) and the transmission of high-definition video. The U.S. military has turned increasingly to the private sector to procure use of its available bandwidth to satisfy military requirements. This reliance on commercial satellites for critical defense operations renders an added dimension of complexity and vulnerability to U.S. national security.
	Essential Civilian	Plastics and telecommunications
Shortfall	**Yes**	There is a net shortfall of 17,002 kilograms.
Supply Risk	**Foreign Reliance**	The United States is 90 percent import dependent on germanium, with principal suppliers including China (51 percent of all imports); Belgium (24 percent); Russia (16 percent); and Germany (6 percent). While domestic production exists, there is currently one producer of high-purity germanium metal in the U.S. market with limited capacity because of the need to meet several competing demands. It is unlikely this producer could meet a surge in demand posited by a national emergency. National defense requirements for IR optical devices and space-qualified solar

		cells are often overshadowed by the private sector requirements for terrestrial solar cells and semiconductors used in LEDs, resulting in production delays and shortages.
Recommended Action	Continue with upgrade portions of existing NDS Program inventory to wafers. Acquire additional germanium metal for stockpile.	

Estimated Demand

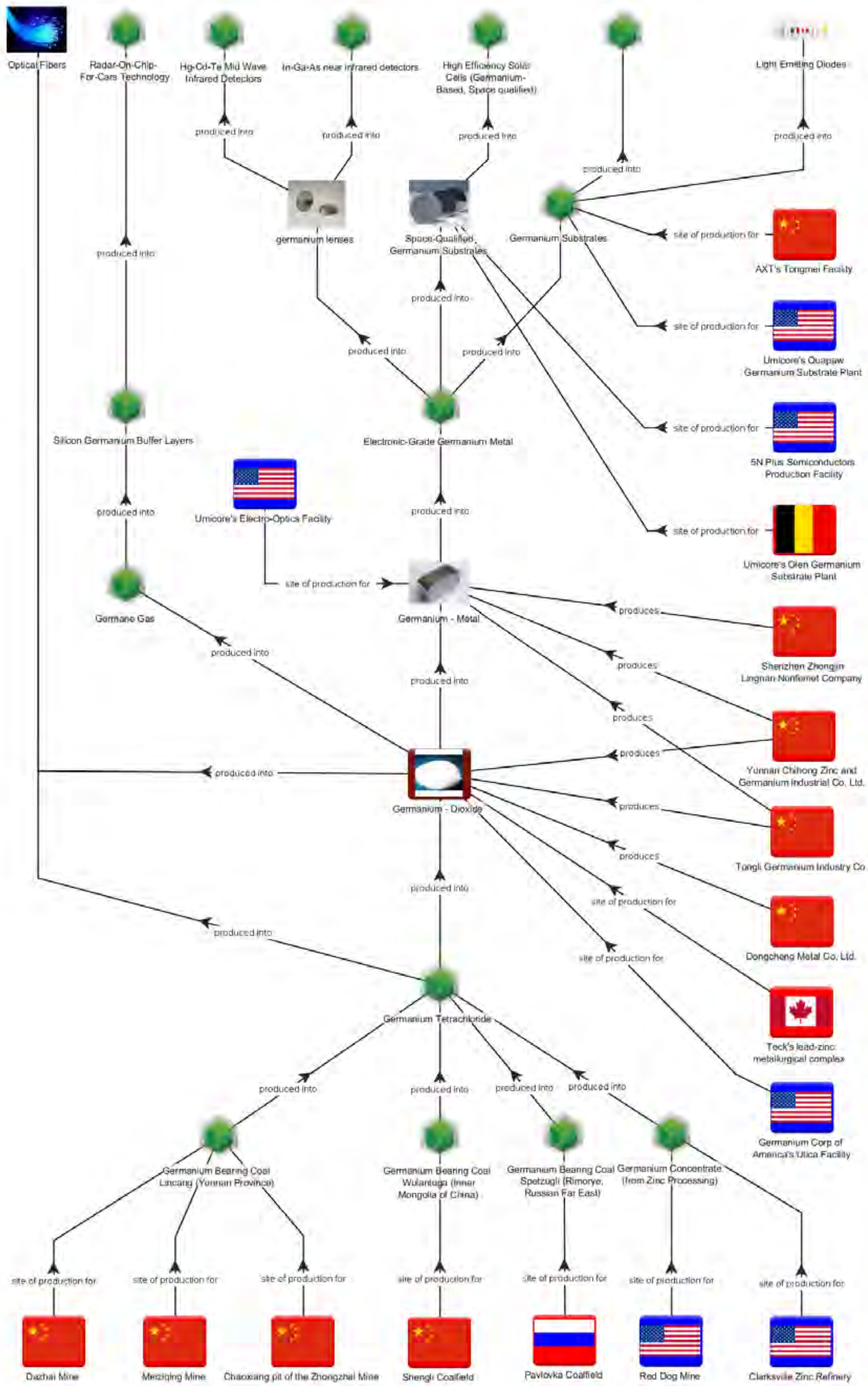
Apparent U.S. consumption of germanium totaled 40,000 kg in 2012, utilizing 30 percent of world supply. Annual demand is expected to grow steadily at 7 percent per year, in line with growth in electronics, fiber optics, IR optics, and Gross Domestic Product (GDP). Demand requirements for DoD and essential civilian applications are markedly different. Demand by the military for high-purity germanium metal for IR devices is 71 percent of the country's total demand, while essential civilian requirements for high-purity germanium metal are less than 2 percent of total demand. Conversely, demand within the essential civilian sector is driven by $GeCl_4$ for fiber optics (64 percent), while less than 20 percent of critical DoD demand for germanium is attributable to fiber optic cables.

Supply Forecast

Currently, Alaska has the sole domestic zinc mine recovering its zinc smelter residues for germanium recovery. The zinc smelter residues are processed in Canada, and are recovered and processed into germanium products and high-purity metal. A second zinc mine with a history of germanium production, located in Washington, was placed on temporary "care-and-maintenance" status due to the drop in zinc prices in 2010. There is also a germanium refinery in Oklahoma that produces germanium for fiber optics, IR devices, and substrates for electronic devices.

Global production of germanium totaled an estimated 156,000 kilograms in 2012, up from 150,000 kilograms in 2011. China is by far the largest producer, with its output totaling 105,000 kilograms in 2012. The United States produced 5,000 kilograms in each of the last 2 years. Global capacity of germanium totaled 293,000 kilograms in 2012. If all planned Greenfield and expansion projects were to reach fruition, global germanium capacity could potentially reach 535,000 kilograms by 2020. However, the majority of this new capacity growth is planned for China and, as such, should be considered tentative at best. Moreover, the specifications for high-purity germanium metal for IR optical devices and space-qualified solar cells can only be met by a few niche suppliers.

Below is a material flow diagram for germanium prepared by ORNL on behalf of the NDS Program



Optical Fibers
Radar-On-Chip-For-Cars Technology
Hg-Cd-Te Mid Wave Infrared Detectors
In-Ga-As near infrared detectors
High Efficiency Solar Cells (Germanium-Based, Space qualified)
Light Emitting Diodes
produced into
germanium lenses
Space-Qualified Germanium Substrates
Germanium Substrates
site of production for
AXT's Tongmei Facility
Umicore's Quapaw Germanium Substrate Plant
5N Plus Semiconductors Production Facility
Umicore's Olen Germanium Substrate Plant
Silicon Germanium Buffer Layers
Electronic-Grade Germanium Metal
Umicore's Electro-Optics Facility
Germane Gas
Germanium - Metal
produces
Shenzhen Zhongjin Lingnan Nonfemet Company
Yunnan Chihong Zinc and Germanium Industrial Co. Ltd.
Tongli Germanium Industry Co.
Dongcheng Metal Co. Ltd.
Teck's lead-zinc metallurgical complex
Germanium Corp of America's Utica Facility
Germanium - Dioxide
Germanium Tetrachloride
Germanium Bearing Coal Lincang (Yunnan Province)
Germanium Bearing Coal Wulantuga (Inner Mongolia of China)
Germanium Bearing Coal Spetzugli (Rimorye, Russian Far East)
Germanium Concentrate (from Zinc Processing)
Dazhai Mine
Menglang Mine
Chaoxiang pit of the Zhongzhai Mine
Shengli Coalfield
Pavlovka Coalfield
Red Dog Mine
Clarksville Zinc Refinery

Graphite, Natural

Description	Most stable form of carbon (C). It has a high melting point, is chemically inert, and is the most electrically and thermally conductive non-metal.	
Applications	Civilian uses include refractories, industrial shapes, lubricants, batteries, friction products such as truck brakes, additives for steel production, pencils, and others. Defense uses of natural graphite include batteries, lubricants, body armor, engine turbine components, coatings for aircraft manufacture, and missile parts.	
Impact during a National Emergency	**Defense**	Modest. Substitution could be utilized to help meet demand.
	Essential Civilian	Recycling could be ramped up to meet demand. Domestic natural graphite mines may be opened.
Shortfall	**No**	Per 2015 NDS Program Report.
Supply Risk	**Foreign Reliance**	No domestic natural graphite production. Major producers of natural graphite include China (70 percent), North Korea (10 percent), and Brazil (8 percent). Synthetic graphite, produced by the United States, Japan, China, the European Union, and India, could be used as a substitute in many applications.
Recommended Action	Continue monitoring efforts.	

Supply Chain

The United States has no domestic production of natural graphite, but it is consumed by roughly 90 U.S. companies. Principal import sources for natural graphite include China (35 percent), Mexico (35 percent), and Canada (20 percent). Most natural graphite takes one of two forms, flake or amorphous. All of our amorphous imports come from Mexico, and uses include steel additives and foundry applications. Main uses of flake graphite include refractories and batteries. Top-quality flake graphite will likely see an increase in demand in the coming years; meanwhile the supply looks to be steady at best, and there are concerns about potential export controls out of China. Expandable graphite is a cutting-edge material made from top-end flake. Uses include flame retardants, solar cells, nanoparticles, and lithium-ion batteries. Graphene, which could also be made from top-quality flake, is a prospective technology hailed as a “super-metal.” Potential uses include armor and other defense applications. Exploration for new sources of flake graphite is under way, mainly in Canada and the United States. In many applications (both amorphous and flake), synthetic graphite can be substituted for natural graphite. However, synthetic graphite is very expensive to produce, and the production process is very lengthy.

Helium

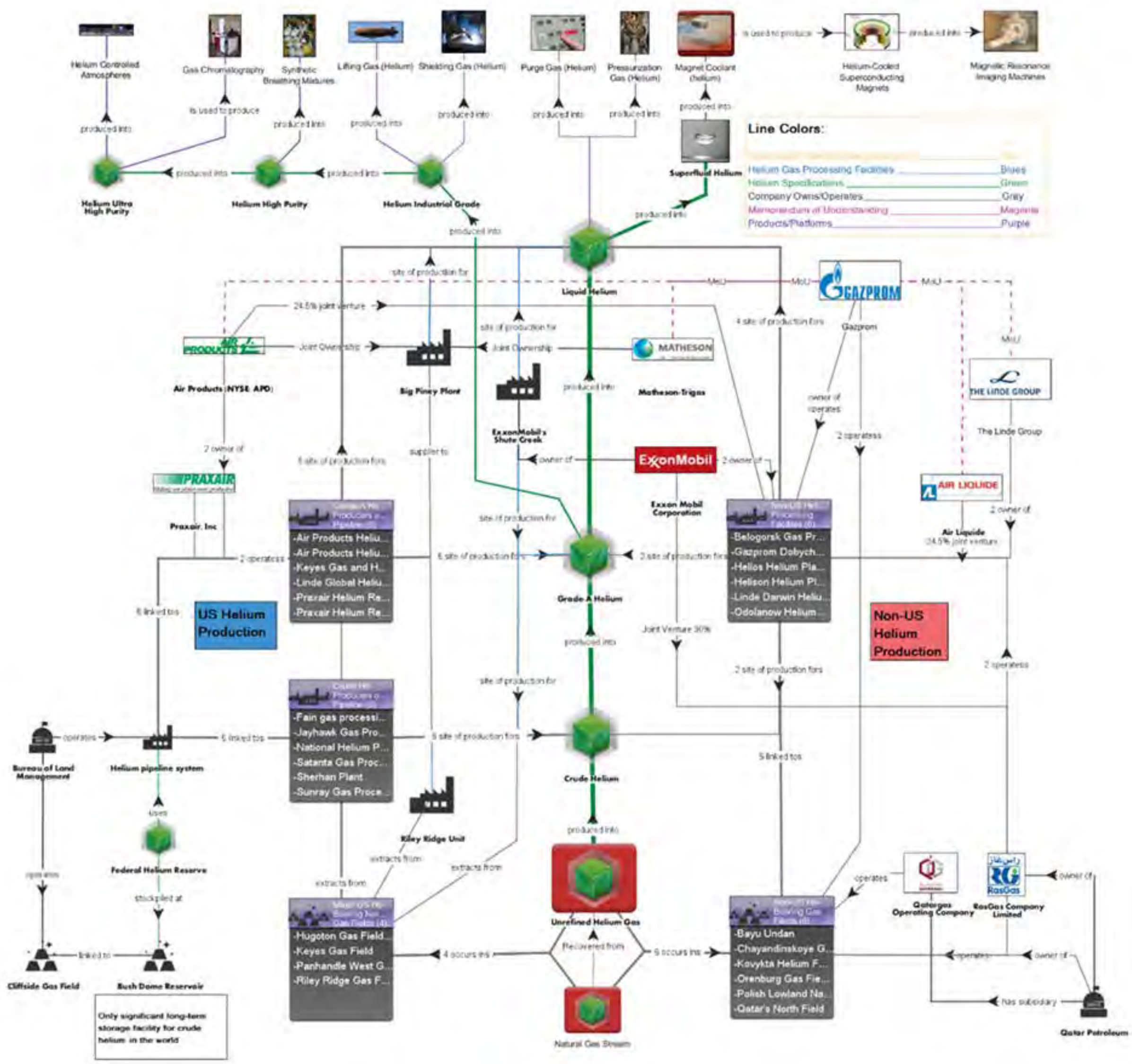
<table>
<tr><td>Description</td><td colspan="2">Helium (He) is an inert gas that has the lowest melting and boiling point (liquid helium boils at -268.9°C/4.2 K/-452°F) of all elements. It is most commonly recovered from natural gas deposits. Helium-3 is a rare isotope of helium whose U.S. supply is managed by the Department of Energy (DoE) isotope program. This section refers only to helium.</td></tr>
<tr><td>Applications</td><td colspan="2">Used for its inert and low-temperature boiling point properties (liquid helium is used as a cooling fluid) in cryogenics, superconducting magnets such as those in medical MRIs, and for space applications.</td></tr>
<tr><td rowspan="2">Impact during a National Emergency</td><td>Defense</td><td>Critical and non-substitutable in space applications, especially liquid helium. The low density and inertness of helium also make it ideal for flotation (balloons, defense aerostats, blimps, etc.) and as a purge gas for rocket motors.</td></tr>
<tr><td>Essential Civilian</td><td>Critical for research and medical applications.</td></tr>
<tr><td>Shortfall</td><td>Possible</td><td>Long-term report currently being prepared for Congress.</td></tr>
<tr><td>Supply Risk</td><td>Single Domestic Point of Failure</td><td>DoD and other federal users depend on the current U.S. stockpile, which is being rapidly drawn down. Reliable supply is particularly important for liquid helium.</td></tr>
<tr><td>Current Actions</td><td colspan="2">Defense Logistics Agency Strategic Materials collaborates with key helium stakeholders within the National Aeronautics and Space Administration (NASA), DoE, Defense Logistics Agency Energy, the Bureau of Land Management, Office of the Secretary of Defense (OSD) Office of Manufacturing and Industrial Base Policy (MIBP), Air Force Space and Missile Center, DoD Missile Defense Agency (MDA).</td></tr>
<tr><td>Recommended Action</td><td colspan="2">Support Bureau of Land Management in report for Congress.</td></tr>
</table>

Supply Chain

Helium can be extracted as a by-product of natural gas from certain natural gas fields that contain sufficient concentrations of helium. The extracted helium must undergo a series of steps to bring it up to the purity levels needed for most applications. Crude helium is an intermediate step, with concentration of between 50 percent and 70 percent helium. Purified helium is 99.95 percent pure or more and may be sold in gaseous or liquid form. The United States, Algeria, Qatar, and Australia all have production facilities that can extract helium from natural gas fields and process it to high-purity gas and liquid. The United States also supplies helium from a helium storage reserve managed by the Bureau of Land Management through the Federal Helium Program.

Recently, helium prices have increased sharply. More concerning, deliveries have in some cases been delayed, especially for small-volume users. Congress has asked the Bureau of Land Management to prepare a report on a federal agency acquisition strategy, which should describe a 20 year federal strategy for securing access to helium.

Below is a material flow diagram for helium prepared by ORNL on behalf of the NDS Program.



Hydrazine

Description	Hydrazine (N_2H_4) is a clear, colorless liquid that produces high-temperature gases upon decomposition.	
Applications	Used as a propellant for rocket propulsion. Also used in airbags and for pharmaceuticals and fungicides and herbicides in agriculture.	
Impact during a National Emergency	**Defense**	While other liquid propellants are used by DoD, hydrazine-based liquid propellants are routinely chosen for small rocket thrusters.
	Essential Civilian	One domestic supplier and a number of foreign suppliers (France and China).
Shortfall	**Possible**	Insufficient data available for modeling through the NDS Program sizing module.
Supply Risks	**Single Domestic Producer**	There is 10 year supply contract in place between DoD and the sole U.S. domestic supplier of propellant hydrazine.
Recommended Action	Continue monitoring efforts.	

Indium

<table>
<tr><td>Description</td><td colspan="2">Indium (In) is a soft silvery-white metal that is mostly produced into indium tin oxide and then used for electrical conduction. Indium tin oxide is also highly transparent in the visual and IR spectrum. Indium is commonly recovered from zinc-sulfide ore.</td></tr>
<tr><td>Applications</td><td colspan="2">Indium is commonly used in the production of LCD displays, LED light bulbs, fiber optics, solder, and alloys. Indium is also used in solar cells, nuclear control rods, and alkaline batteries. In defense applications, indium is used in IR imaging and communications systems.</td></tr>
<tr><td rowspan="2">Impact during a National Emergency</td><td>Defense</td><td>Indium is used in IR imaging systems and in communications systems.</td></tr>
<tr><td>Essential Civilian</td><td>Commonly used for optical coatings in LCDs and in the production of LEDs.</td></tr>
<tr><td>Shortfall</td><td>No</td><td>Per the 2015 NDS Program study, no shortfall determined.</td></tr>
<tr><td>Supply Risk</td><td>Foreign Reliance</td><td>The United States does not mine indium; however, two domestic facilities have the capability to upgrade low-grade indium to high-purity forms. China dominates the world's production of indium. Import reliance is listed in descending order: Canada, China, Japan, Belgium, and others.</td></tr>
<tr><td>Current Action</td><td colspan="2">The NDS Program does not contain indium.</td></tr>
<tr><td>Recommended Action</td><td colspan="2">Continue monitoring efforts.</td></tr>
</table>

Supply Chain

The US is fully dependent on imports of indium to satisfy demand. US indium sources are diverse and include Canada (24 percent), China (23 percent), Japan (13 percent), Belgium (11 percent) and other countries (29 percent). Indium is typically imported in its desired form; however, two domestic facilities are capable of processing low-grade indium into a high-purity form. China has the largest estimated reserves of indium.

Indium is typically produced as a by-product of processing lead-zinc concentrates. Major indium producers are located in Canada. According to the USGS 2012 Minerals Yearbook, Japan had the capacity to produce 200 metric tons/year of secondary indium. Indium can also be recycled and is most commonly recovered from indium tin oxide in China, Japan, and the Republic of Korea. Indium is stored and traded in China. As of 2014, indium inventories have been accumulating in exchange warehouses.

Estimated Demand

Overall, U.S. demand for indium is sluggish. The 5 year demand forecast predicts low to minimal growth, hovering around 100–110 metric tons (MT). In 2009–2013, U.S. consumption remained flat. U.S. demand is primarily driven by LCDs. Indium is used for electrical conductive purposes in flat panel displays, to produce solders, alloys, electrical components, and semiconductors, and for research purposes. U.S. imports of unwrought indium metal and indium powder decreased -25 percent in 2011–2012 (146 metric tons to 109 metric tons). The price of indium fluctuated throughout the year but ended with a 6 percent decrease in price.

Supply Forecast

At this time, there is no evidence of constrained indium supplies. In 2012, global indium tin oxide production capacity increased by 7 percent; however, actual production did not appear to increase. At this time, there is no evidence of supply disruptions. In the past, though, the indium supply chain appeared to be vulnerable to supply disruption. As a result, indium tin oxide substitutes were developed. Antimony tin oxide coatings have been developed for LCD glass to replace indium tin oxide coatings. For solar cells, carbon nanotube coatings have been developed to replace the indium tin oxide. Gallium arsenide can be substituted for indium phosphide in many situations for solar cells and semiconductors. Indium in nuclear reactor control rod alloys may be replaced by hafnium.

Iridium

Description	Iridium (Ir) is very brittle silver-white metal. Iridium becomes very ductile and can be worked in white heat (2,200°F to 2,700°F). It is considered to be one of the most corrosive-resistant metals known.	
Applications	The limited malleability of iridium, which makes it very difficult to machine, limits its applications. Iridium is primarily used as a hardening agent for platinum. Platinum-iridium alloys are used to make crucibles for growing high-purity sapphire single crystals for LEDs. Iridium is also used in other high-temperature equipment, in catalysts, spark plug tips, alloys, and electrical contacts.	
Impact during a National Emergency	**Defense**	Due to iridium's unique properties, substitution may be challenging for applications such as long-life aircraft engines, deep-water pipes, satellites, a hydrazine-based propellant catalyst, satellite and launch vehicles, and rocket combustion chambers.
	Essential Civilian	Catalysts are designed for reuse but often become deactivated over time. Iridium used in catalysts, spark plugs, and crucibles can be recycled but not necessarily as pure iridium metal.
Shortfall	**No**	Per 2015 NDS Program Study.
Supply Risk	**Foreign Reliance**	Largest known primary reserve and source of iridium is South Africa, with a few significant deposits located in Russia.
Current Action	The NDS Program contains 489 troy ounces ($458,000) of iridium.	
Recommended Action	Continue monitoring efforts.	

Supply Chain

Iridium is a silver-white platinum group metal that is very brittle and nearly impossible to machine. Iridium is mined with other platinum group metals (PGM) and can also be retrieved as a by-product from nickel and copper.

The United States is highly reliant on worldwide iridium sources. Domestically, there are two mines in south central Montana that primarily produce platinum and palladium. The United States currently has an iridium stockpile in the NDS Program.

As of 2011, U.S. iridium import sources included South Africa (64 percent), United Kingdom (19 percent), Germany (8 percent), and other countries (9 percent). These iridium statistics do not separately identify the original source of the raw ore or special forms. Various countries such as Myanmar, Brazil, and England process PGMs from raw ore or recycled products but do not have mine iridium.

Iridium is primarily mined in South Africa. The South African supply of iridium is subject to disruptions from worker strikes and disputes at various mining companies, and rivalry between two unions caused an increase in cost and higher metal prices. Russia and Canada both possess large nickel and copper deposits that contain significant amounts of iridium. The average annual prices for PGMs, including iridium, continued to decrease from 2012 to 2013 due to economic concerns. At this time, there is no evidence of constrained iridium supplies for the United States.

Estimated Demand

U.S. iridium demand is highly erratic. In 2012–2013, U.S. iridium imports for consumption increased +22 percent following large declines in 2011–2012 (-56 percent) and 2010–2011 (-21 percent).

The electrical end-use sector drives U.S. demand. In 2010, iridium prices increased +150 percent because of developments in the LED field. LED manufacturing uses iridium crucibles to produce crystals for backlit screens in consumer products. Prices stabilized in 2012–2013 as LED manufacturers sufficiently balanced their iridium crucible supply with production demand. Anecdotal evidence suggests future U.S. demand may decline in response to a decreased need for iridium crucibles.

Worldwide, iridium demand increased approximately 3 percent in 2012–2013 (6,000 kg to 6,200 kg). Global demand may be divided into four groups, three of which experienced increasing demand: chemical (5 percent), electrical (25 percent), and other (6 percent), while the electrochemical (16 percent) industry experienced a decrease. Iridium demand may decline in the future because of an expected decrease in demand from China.

Supply Forecast

Supply data of iridium is grouped with "other PGMs," which also include rhodium, ruthenium, and osmium (all PGMs except platinum and palladium). In 2011–2012, other PGM production declined by 7 percent. Other PGM data for 2013 is not yet available but is believed to have increased. The 5 year supply forecast for other PGM indicates worldwide production hovering between 65 and 72 MT. The United States is expected to remain dependent on foreign sources of iridium.

South Africa supplies approximately 78 percent of the world's iridium. In 2014, South Africa PGM production was disrupted because of a large-scale mining strike. Anecdotal evidence suggests the South Africa mining sector may experience some corporate restructuring and layoffs as a result of the 2014 strike.

Lead

<table>
<tr><td>Description</td><td colspan="2">Lead (Pb) is a heavy metal with a low melting point.</td></tr>
<tr><td>Applications</td><td colspan="2">Lead-acid batteries for automotive, lighting, and industrial applications for uninterruptible power supply equipment; solder; ammunition; cable sheeting; and shielding for X-ray machines.</td></tr>
<tr><td rowspan="2">Impact during a National Emergency</td><td>Defense</td><td>Possible dislocation of high-purity lead supplies for thin-plate pure lead (TPPL) batteries used in aircraft and some navy vessels. High-purity lead supplies after 2014 are still not known to the NDS Programs.</td></tr>
<tr><td>Essential Civilian</td><td>None</td></tr>
<tr><td>Shortfall</td><td>No</td><td>Per 2015 NDS Program Report.</td></tr>
<tr><td>Supply Risk</td><td>Single Domestic Point of Failure for Defense</td><td>The United States mines primary lead at six locations in Missouri and also in Alaska and Idaho. The United States is a major supplier of secondary lead through a robust lead-acid battery recycling and import industry. Using USGS data (2014 Mineral Commodity Summary), the United States shipped an estimated 93.1 million lead-acid automotive batteries in the first 9 months of 2013, a slight increase from the same period in 2012.

A domestic primary lead smelter that supplied the U.S. DoD was closed at the end of 2013, in accordance with an agreement with the U.S. Environmental Protection Agency (EPA). After the closure, lead concentrate produced at U.S. mines may be exported for refining.</td></tr>
<tr><td>Current and Recommended Action</td><td colspan="2">Action being undertaken by impacted agencies.</td></tr>
</table>

Estimated Demand

Citing data from the International Lead/Zinc Study Group (ILZSG), the USGS reported a world consumption of refined lead of 11.0 million metric tons in 2013, an increase of 5 percent from that in 2012. China is by far the largest user of lead worldwide with consumption totaling an estimated 5.0 million metric tons in 2013, representing approximately 45 percent of global usage. Reported consumption of refined lead in the United States totaled 1.4 million metric tons in 2013, up from 1.36 million metric tons in 2013. Other notable consuming countries include India, South Korea, Japan, and Brazil, with a combined usage that is about equal to that of the United

States. As mentioned previously, lead-acid batteries account for the overwhelming majority of lead usage globally and in the United States. Other end uses include solder, ammunition, and cable sheathing.

Supply Forecast

World lead mine production totaled 5.4 million metric tons in 2013, representing a 4.4 percent increase over 2012 levels. According to the USGS, mine production in China surged by 200,000 metric tons in 2013 to an estimated total of 3.0 million metric tons, while mine production in Australia advanced by 42,000 metric tons because of the restart of a lead mine that produces 85,000 metric tons per year. Meanwhile, lead mine production in the United States totaled 340,000 and 345,000 metric tons in 2012 and 2013, respectively. World refined lead production increased by 5 percent in 2013 to a total of 11.0 million metric tons. On a global level, the split between primary and secondary refined lead is approximately 50:50 but slightly favors primary lead. Chinese refined lead production totaled approximately 5.2 million metric tons in 2013 as the startup of new smelters outpaced the closure of older capacity equipment. Because of its large reserves, primary lead comprises approximately 68 percent of Chinese refined lead production. This contrasts with the United States, where primary refined lead makes up only 9 percent of all refined lead production. Australian mine and refined lead production is on the lower end of the scale despite the fact that 40 percent of world lead reserves are located in Australia. This seeming anomaly is borne out in Australia's lead mine and refined production, which totaled just 690,000 metric tons and 232,000 metric tons, respectively, in 2013.

Lithium

Description	Lithium (Li) is a white-silver metal and is highly reactive and flammable. It is the lightest metal.	
Applications	Lithium metal is used mainly in batteries (thermal, rechargeable, non-rechargeable), aluminum lithium alloys for aircraft structure, air purification for submarines, tires for ground vehicles, lubricants and grease, glass and ceramics, aluminum production, polymers, pharmaceutical and chemical industries.	
Impact during a National Emergency	**Defense**	Required for repairs of fighter jet structure, safety of soldiers (thermal batteries), batteries in electronics. Substitution limited and must be considered on individual basis: alternative battery technologies generally have lower power density, but composites are possible substitutes for aluminum lithium alloys.
	Essential Civilian	Major concern is for portable consumer electronics, which almost all utilize lithium-ion batteries.
Shortfall	**No**	Lithium metal and non-qualified lithium compounds are not in shortfall. Per 2015 NDS Program study.
Supply Risk	**Limited**	Domestic production of lithium minerals is not sufficient to cover U.S. needs (import reliance > 70 percent in 2012). Key foreign producers are Chile and Australia. Recycling not currently a significant supply option. There is presently a global surplus in the production of lithium, although the actual surplus production of lithium carbonate could disrupt the market and force some producers to exit it. It is more profitable to produce lithium carbonate than the lithium chloride needed for metal production. Therefore, there is concern that an insufficient supply of lithium chloride would result and impact the availability of lithium metal.
Recommended Action	Continue monitoring efforts. Please refer to lithium-ion precursors and aluminum lithium alloy sections for details on the specific issues with this downstream supply of chain-material-containing lithium.	

Supply Chain

Globally, there are four major lithium producers, however a large number of junior companies are entering or trying to enter the market around the world, and many are from North America. Of these, eight projects by North America companies are at or above the stage of pilot plant, and three are in production.

The world reserves are located mainly in Chile, China, Argentina, and Australia. The majority of the production originates from salars (~60 percent) located mainly in South America and hard rock deposits (~26 percent) prevailing in Australia, China, and Canada.

The world production of lithium in 2012 was estimated to be ~37,000 MT of lithium metal content. Estimates are often vary among sources of information due to the opacity of the market and the number of forms of lithium element that exist. The lithium market has expanded significantly each most years since 2001 and many experts forecast an increase around 7 percent to ~9 percent over the next few years.

There are reportedly eight major lithium metal producers in the world. The largest known producers are in China. In 2011, China exported ~2,000 MT of lithium metal according to Roskill.

The battery sector is an increasing market requiring pure lithium. The automobile sector is using the largest quantity per product. The number of automobiles using batteries is increasing although many studies agree that there is not a supply issue in the near or middle term; actually, there is presently a surplus of lithium concentrates production. The lithium industry is expanding its production capacities, and the juniors who are able to enter the market will provide additional materials.

Recycling of lithium-containing batteries is an already established market, but in some processes, the lithium was not collected. New entrants are recycling lithium batteries to retrieve the lithium.

Experts are forecasting that growth in the demand for the different lithium market sectors should be between 2 and 5 percent per year except for batteries (around 15 to 19 percent per year), and for the production of aluminum lithium alloy, a growth of ~6 to 10 percent per year was announced. However, because of new processes used in the production of aluminum, the demand for lithium in that sector should decrease significantly or even disappear.

Estimated Demand

The global demand for lithium is difficult to establish because the market is opaque. In 2011, the distribution of lithium per sector was showing that the greatest use was in glass and ceramics (~30 percent), followed by batteries (~22 percent), and lubricants (~11 percent). Many other applications represented less than 4 percent each, with the production of lithium metal being evaluated around 4 percent. It is expected that the battery sector will surpass the glass industry within a couple years (2015 forecast is 26 percent glass and 33 percent batteries)

The increased use of aluminum lithium alloy in the structure of airplanes is going to increase the demand for lithium metal; however, one must keep in mind the low lithium content of that type of alloy (~1.8 percent in the newest alloys). For example, in 2007, the lithium used for the alloy was ~70 MT for about 5,000 MT of alloy.

Supply Forecast

All experts agree that there is no issue with the supply of lithium in general, but the situation of surplus does not apply to all forms of lithium. The higher commercial return for companies producing lithium carbonate rather than lithium chloride causes concern regarding a possible lack of available lithium chloride in the future.

Lithium-ion Precursors

Description	Lithium-ion precursors are materials used in the cathode of lithium-ion rechargeable batteries and include three materials: meso carbon micro beads (MCMB), lithium cobalt oxide (LCO) and lithium nickel cobalt aluminum oxide (LNCAO).	
Applications	These materials are used in Space/Satellite communications, the Global Hawk, JSF/F-35, and space tracking and surveillance system.	
Impact during a National Emergency	**Defense**	DoD requires performance proven lithium batteries using these precursor materials. These platforms provide the military forces and intelligence needed to deter war and to protect the security of the United States.
	Essential Civilian	None. Could substitute different battery types and qualification is not needed.
Shortfall	**Yes**	Stockpile a supply of MCMB, LCO and LNCO to produce a one year supply by acquiring over five years.
Supply Risk	**Domestic Single Point of Failure**	Title III, Defense Production Act, helped establish a manufacturing facility located in Sylmar, California. This facility is the only global producer of MCMB, LCO and LNACO. Since components in NSS applications must be life cycle performance proven; substitutes cannot be readily applied unless they are pre-certified.
Current Action	Per FY 2014 NDAA, approval for stockpiling lithium-ion precursors was obtained and is ongoing.	

Supply Chain

The United States is currently working down an exhaustible supply of MCMB, LCO and LNCAO obtained from Osaka Gas before they ceased production. The Defense Production Act Title III established a domestic production capability. Reserve inventories of MCMB, LCO or LNCAO have not been produced to date. Surge production capabilities are untested, and there is one lone global producer and a single point of failure in this crucial supply chain.

Magnesium

Description	Magnesium (Mg) is a lightweight alkaline earth metal and the eighth most abundant element. Used in metal alloys and as a stand-alone metal. In nature, magnesium is needed for plants and nutrition.	
Applications	Magnesium is a critical component in the production processes of titanium, uranium, and beryllium. It is also used as an alloy material in beverage cans, household appliances, and other consumer goods. In addition, magnesium is used as a structural lightweight material in the automotive and aerospace industries. Iron and steel desulfurization is another major application. Military applications include helicopter transmission housings, armor applications, broadcast and wireless communication equipment, radar equipment, torpedoes, anti-tank ammunition rounds, batteries, flare and ordnance applications, and IR and missile countermeasures. Magnesium is also an alloy component used for aircraft, vehicle engine casings, and missile construction. Some metal reduction is for military applications.	
Impact during a National Emergency	**Defense**	Moderate. Military needs would take priority over civilian uses. No defense shortfall is anticipated.
	Essential Civilian	Moderate. Secondary supply and substitution could compensate in many applications.
Shortfall	**Yes**	There is a net shortfall of 5,422 metric tons.
Supply Risk	**Single Domestic Point of Failure**	Single U.S. producer of primary magnesium metal. Import reliance with top producers outside the continental United States (OCONUS) include: China 87 percent, Russia 4 percent, Israel 3 percent, and Kazakhstan 3 percent.
Recommended Action	Purchase up to 5,422 MT for stockpile, at a projected cost of up to $24.25 million.	

Supply Chain

Magnesium is found in the following minerals: dolomite, magnesite, brucite, carnallite, talc, and olivine. It is also commonly obtained from seawater or well/lake brines. In the United States, the one pure magnesium metal producer uses an electrolytic process on Great Salt Lake brines. Principal import sources for magnesium metal are Israel (33 percent), Canada (25 percent), and China (8 percent). Following a World Trade Organization complaint filed by the European Union, the United States and Mexico, China removed a 10 percent export tax on magnesium metal.

Domestically, primary magnesium is most commonly used as a reducing agent in the production of titanium and other metals. It is also consumed heavily as part of aluminum alloys that are used for packaging, such as beverage cans, and in transportation. In smaller quantities, magnesium is used for castings and wrought structural products and for desulfurization of iron and steel. The use of magnesium in automobile parts is expected to increase in order to help decrease vehicle weight and increase fuel efficiency. Magnesium use will likely increase along with titanium demand, as titanium production using the Kroll process uses liquid magnesium as a reducing agent.

When necessary, aluminum and zinc can be substituted for magnesium in castings and wrought products. In the desulfurization of iron and steel, calcium carbide can be substituted. Secondary supply can be used as a substitute for primary supply in some applications. In 2013, approximately 25,000 tons and 55,000 tons of magnesium were recovered from old scrap and new scrap, respectively. Metal reduction is the application most vulnerable to supply disruptions. There is no substitute for magnesium in current titanium and beryllium production processes, where secondary magnesium cannot replace primary magnesium.

Manganese Ore

Description	Manganese (Mn) is the 12th most abundant element. Common ores, contain 20+ percent manganese: pyrolusite, braunite, and psilomelane.	
Applications	Manganese ore is a precursor for electrolytic manganese metal and ferromanganese. It may also be directly used in steel-making, in primary aluminum production, in non-rechargeable batteries, fertilizers, animal feed, brick colorant, welding, and as an additive in unleaded gasoline.	
Impact during a National Emergency	**Defense**	Moderate. There is no direct substitute of manganese in the production of steel; however, substitution is possible in most other applications.
	Essential Civilian	Moderate. There is no direct substitute of manganese in the production of steel; however, substitution is possible in most other applications.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risks	**Foreign Reliance**	No domestic production of ore with manganese content of 35 percent or more. Complete foreign reliance on large producers. Gabon (60 percent) and South Africa (30 percent) are the largest import sources for the United States.
Current Action	The NDS Program contains some excess manganese ore inventory.	
Recommended Action	Continue to reduce excess inventory in the NDS Program.	

Supply Chain

The United States has only one mine, which produces a small amount of very low grade manganiferous material with a manganese content of 5 percent; this material is mostly used in coloring brick. The leading countries in manganese production include South Africa (21 percent), Australia (20 percent), China (18 percent), Gabon (12 percent), and Brazil (8 percent). Burma, Mexico, Ukraine, and Malaysia are minor producers of manganese ore.

Manganese ore consumption, both domestic and global, typically follows that of steel production, which has grown at a rate of 1 percent to 2 percent in last 5 years. Manganese consumption for non-metallurgical components, such as batteries, may be growing faster than that for steel production but only has a minor effect on overall manganese demand. No significant jump in the demand for manganese ore is seen in the near future.

The United States relies 100 percent on imports for its apparent consumption of manganese ore. Land-based manganese ore resources are large but concentrated. South Africa and Ukraine account for 75 percent and 10 percent, respectively, of the world's manganese resources. Demand for the supply of manganese ore should be tracked fairly closely.

Manganese, Electrolytic Manganese Metal

Description	Electrolytic manganese metal (EMM) has a purity of more than 99 percent. It is produced using a hydrometallurgical process and is used for aluminum alloys, super alloys, and some steel alloys.	
Applications	EMM is used in steel alloys, aluminum alloys, and super alloys.	
Impact during a National Emergency	**Defense**	Significant. There is no direct substitute for manganese in the production of aluminum alloys and some types of steel alloys.
	Essential Civilian	Significant. There is no direct substitute for manganese in the production of aluminum alloys and some types of steel alloys.
Shortfall	**Yes**	There is a net shortfall of 1,480 short tons.
Supply Risks	**Complete Foreign Reliance**	There is no domestic production of EMM. Over 95 percent of worldwide production occurs in China. South Africa is currently the only other producer.
Current Action	In-depth supply chain assessment is ongoing.	
Recommended Action	Purchase up to 1,480 ST for NDS Program at a projected cost of up to $4 million.	

Supply Chain

Electrolytic manganese metal is produced from manganese ore. Manganese ore is widely available. However EMM is produced almost exclusively in China (98 percent). The United States relies completely on imports, having no domestic suppliers. A few new projects under construction in Europe, Asia, and Africa are slated to come online in the 2015–2017 time frame. Should all of these projects begin operation, China's share of world capacity would fall to 94 percent. Recycling of EMM is scant. There are potential substitutes for only some applications. Domestic production capacity for electrolytic manganese dioxide (EMD) could potentially be quickly reconfigured to produce EMM; EMD is used in lithium ion and other types of batteries.

Manganese, Ferromanganese and Silicomanganese

Description	Manganese (Mn) is the 12th most abundant element. Common ores, with 20+ percent manganese content, are pyrolusite, braunite, and psilomelane. Ferromanganese and silicomanganese are alloys with 30 to 80 percent manganese. Ferromanganese is produced by heating iron oxide and manganese oxide in the presence of carbon. Silicomanganese is produced in a similar way but with the addition of silicon dioxide.	
Applications	Ferromanganese and silicomanganese are essential components in the steel manufacturing process.	
Impact during a National Emergency	**Defense**	Moderate. There is no direct substitute of manganese in the production of steel.
	Essential Civilian	Moderate. There is no direct substitute of manganese in the production of steel.
Shortfall	**No**	Per 2015 NDS Program report.
Supply Risks	**Foreign Reliance**	Domestic production exists; however, the majority of U.S. demand is met by imports. China is the world's largest producer (55 percent), but supplies are available from numerous countries. South Africa provides somewhat more than half of U.S. imports. Other sources include Australia, Mexico, Ukraine, and Norway.
Current Action	The amount of ferromanganese in the NDS Program is 369,000 ST.	
Recommended Action	Continue with disposal of excess ferromanganese from the stockpile.	

Supply Chain

Ferromanganese, silicomanganese, or ferrosilicomanganese are produced domestically by two companies. Manganese consumption, both domestic and global, typically follows that of steel production, which has grown at a rate of 1 percent to 2 percent in last 5 years. No significant jump in the demand for manganese is seen in the near future.

Natural Rubber

Description	Natural rubber is harvested mainly from the *Hevea brasiliensis* tree in the form of latex – a sticky, milky colloid drawn off the tree by making an incision into the bark and collecting the fluid. While indigenous to the Amazon, over 90 percent of natural rubber is now produced in Southeast Asia due to the favorable climatic conditions required for rubber tree growth. After tree tapping, forming, and drying, natural rubber sheets are smoked and packed into bales for shipping to world markets.	
Applications	Tires account for 70 percent of natural rubber demand. Other applications include industrial hoses and gaskets, dental/medical supplies, sporting goods, toys, shoes and apparel. Defense applications include tires, firearms training, readiness training, sonar buoys, explosives, and compression bandages.	
Impact during a National Emergency	**Defense**	Tires, medical products
	Essential Civilian	Tires, medical products
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risk	**Complete Foreign Reliance**	Foreign reliance on Thailand and Indonesia, which account for a combined 58 percent of global production. The United States does not produce natural rubber.
Recommended Action	Prepare a supply-chain analysis to confirm whether sufficient capacity exists in the synthetic rubber market to serve as a substitute for natural rubber. It is proposed that the analysis would focus on the Department's requirement for tires since this comprises two-thirds of global natural rubber consumption.	

Estimated Demand

World consumption of natural rubber totaled approximately 11.4 million metric tons in 2013, rising 2.9 percent from the previous year's level. Usage in Asia/Oceania led the way with consumption totaling nearly 8.3 million metric tons or 72 percent of the total. Consumption of natural rubber within China totaled approximately 3.8 million metric tons, accounting for 45 percent of the usage in Asia/Oceania. Consumption in the European Union totaled about 1.1 million metric tons in 2013, which was about the same as that for 2012. Consumption statistics for North America, Latin America, and Africa were discontinued after 2012 and are not available for 2013. However, annual consumption in these three regions averaged 985,000 metric tons, 550,000 metric tons, and 90,000 metric tons, respectively, over the years 2008–2012. Consumption of natural rubber in China is expected to reach 6.5 million metric tons by 2020, accounting for 41 percent of world natural rubber consumption in that year. India is also expected to see strong growth in the use of rubber, with consumption forecast to grow from

960,000 metric tons in 2011 to 1.65 million metric tons in 2020. Growth in each country's auto and truck sector is expected to drive the majority of this growth. As mentioned previously, tires represent approximately 70 percent of all natural rubber consumption, with the balance consumed in the general rubber goods (GRG) segment.

Supply Forecast

Production of natural rubber totaled 12.04 million metric tons in 2012, representing a 3.8 percent increase from the 2012 level. Production is concentrated in Southeast Asia, specifically in Thailand, Indonesia, Vietnam, Malaysia, and India which together account for 80 percent of global production. Thailand is the world's largest producer of natural rubber, with its output totaling nearly 3.5 million metric tons in 2012 for a 31 percent share of global output. This was followed by Indonesia at 3.015 million metric tons for a 27 percent share, and then by Vietnam, Malaysia, and India, each of which accounted for 8 percent of global output.

Over the past 50 years, global production of natural rubber has increased from 2 million metric tons in 1961 to nearly 12 million metric tons as of 2012 – a six-fold increase. The production and usage of rubber during this time has largely followed the development of the automobile and industrial production. From 2000–2012, growth in output accelerated (with the exception of 2009 when demand contracted in the wake of the global financial crisis) because of the rapid industrialization of China and growth of the country's auto and truck industries. As mentioned previously, China and India will require an additional combined 2.5 million metric tons of natural rubber by 2020, necessitating additional investments in natural rubber production and/or increases in productivity and recycling. Likely candidates for expansion include Vietnam, Malaysia, and India.

However, investment in new supply is not likely to occur in the near term as the industry attempts to overcome a market surplus and depressed prices. According to the International Rubber Study Group (IRSG), the surplus in the natural rubber industry totaled 644,000 metric tons in 2013 and is expected to total about 430,000 metric tons in 2014. If 2014 is another surplus year, this will mark the fourth straight year of surpluses in the natural rubber market. The world's largest producer, Thailand, is said to be sitting on a stockpile of 220,000 metric tons, representing 1.5 percent of global annual output. There had been talk among the Thai Junta Team to release these stockpiles as a way of shedding the surplus production. However, such a move would depress prices, which are down by over 26 percent already this year according to the Association of Natural Rubber Producing Countries.

Nickel

Description	Nickel (Ni) is a silvery-white, lustrous metal that is hard, malleable, and ductile.	
Applications	Turbines blades for land-based turbines, jet aircraft engines, and large-scale power generation. Liquid gas storage, high-speed steels, maraging steels (iron nickel alloys), permanent magnets (Alnico), nickel-titanium memory alloys (eyeglass frames), batteries (nickel cadmium (NiCd), nickel metal hydride (NiMH), reforming hydrocarbons, production of fertilizers, pesticides, and fungicides.	
Impact during a National Emergency	**Defense**	Major component in nickel superalloys for high-temperature sections of jet engines, maraging steel (aerospace and military use). Substitution challenging for defense, but recycled supplies can be used.
	Essential Civilian	Nickel superalloys used to improve efficiency of large-scale power generation, corrosion-resistant alloys for petroleum production and refining, and batteries. Substitution possible in most applications.
Shortfall	**No**	Per 2015 NDS Program study.
Supply Risks	**Limited Foreign Reliance**	Single domestic mine starting production in 2014 with remaining U.S. production through recycling, satisfying 43 percent of apparent consumption. U.S. imports from Canada, Russia, Australia, and Norway.
Recommended Action	Continue monitoring efforts.	

Supply Chain

Nickel is a silvery-white, lustrous metal that is hard, malleable, and ductile. On Earth's crust, nickel averages 80 ppm and is greatly concentrated in the ore. Nickel occurs in nature principally as oxides, sulfides, and silicates. Native nickel is always found in combination with iron.

The United States imports nickel from Canada (36 percent), Russia (17 percent), Australia (11 percent), and Norway (10 percent). The United States did not have any active nickel mines in 2011. An underground chalcopyrite-pentlandite mine, however, was being developed in Michigan and was scheduled to be in full production by 2014. Three mining projects were also in various stages of development in northeastern Minnesota. About 95,000 tons of nickel was recovered from purchased scrap in 2012, which represented about 43 percent of secondary plus apparent primary consumption.

To offset high and fluctuating nickel prices, low-nickel, duplex, or ultrahigh-chromium stainless steels are being substituted for austenitic grades in construction. Nickel-free specialty steels are sometimes used in place of stainless steel in the power-generating and petrochemical industries. Titanium alloys can substitute for nickel metal or nickel-based alloys in corrosive chemical environments. Cost savings in manufacturing lithium-ion batteries allow them to compete against NiMH in certain applications.

Estimated Demand

Approximately 48 percent of the primary nickel consumed went into stainless and alloy steel production, 39 percent into nonferrous alloys and superalloys, 10 percent into electroplating, and 3 percent into other uses. End users of nickel were as follows: transportation, 30 percent; fabricated metal products, 14 percent; electrical equipment, 12 percent; petroleum industry, 10 percent; chemical industry, construction, household appliances, and industrial machinery, 8 percent each; and other, 2 percent. Demand for nickel in the transportation sector is also expected to increase. North American usage of nickel- and cobalt-base superalloys was expected to escalate between 2013 and 2020, largely because of an increasing demand for new jet aircraft that have more-fuel-efficient engines.

Global demand for electricity continues to increase and is accelerating as the population of the world increases. To meet demand, utilities will need to build more generating capacity, irrespective of whether the plants operate on fossil fuels, renewable energy (geothermal, solar, or wind), or nuclear fuels. All of this capacity would require large tonnages of nickel-bearing stainless steel and superalloys. Significantly higher gasoline prices could encourage the replacement of conventional automobile steel frames with lighter ones fabricated from stronger stainless steel containing nickel.

Supply Forecast

The 2014 USGS Mineral Commodity Summary estimates global mining production of nickel to increase in 2013 from 2012. Philippines and Indonesia have the largest nickel mine production and account for 15 percent of the world's production. The United States is expected to be dependent on foreign sources of refined metal and ferronickel for at least the next 25 years, even if all four of the current copper-nickel mining projects in the Lake Superior region come to fruition. The ongoing expansion of nickel laterite mining operations in Brazil, Indonesia, New Caledonia, and other tropical countries will help meet the increasing demand for nickel worldwide.

Niobium: Metal and Ferroniobium (Formerly Columbium)

Description	Niobium (Nb) is a ductile paramagnetic metal that is also corrosion resistant and exhibits superconductivity properties. Ferroniobium contains 60 to 70 percent niobium, and the rest is mostly iron.	
Applications	Alloying element for steel, stainless steels, superalloys, tool bits, surgical implants, and superconducting magnets. Superalloys are used in air transport, gas turbines, heat-resistant combustion equipment, tool bits and cutting tools, nuclear industries, surgical implants, superconducting magnets.	
Impact during a National Emergency	**Defense**	Used in superalloys for turbine engines, rocket sub-assemblies, memory metal for hydraulic couplings.
	Essential Civilian	Other materials may be substituted for niobium, such as molybdenum, tantalum, and ceramics, in most applications but with a possible loss in performance or increase in cost.
Shortfall	**Yes**	Per 2011 NDS Program Report.
Supply Risk	**Complete Foreign Reliance**	No domestic mine production with imports mostly from Brazil (84 percent) and Canada (10 percent). One company dominates the global niobium market
Current Action	The NDS Program contains approximately 10 metric tons of niobium metal ingots.	
Recommended Action	Continue with purchase of ferroniobium as approved in the FY 2014 NDAA.	

Supply Chain

Niobium is a lustrous, grey, ductile, paramagnetic metal. In elemental form, the melting point of niobium is 2,468°C. Compared to other refractory metals like tantalum and tungsten, niobium has a low density. Niobium is estimated to make up about 8 ppm of the Earth's crust by weight. Niobium is often found in minerals that also contain tantalum, such as columbite and columbite-tantalite. Less common oxides of niobium are tapiolite, ixiolite, and minerals of the pervoskite group.

Brazil is the leading producer of niobium and ferroniobium, an alloy of niobium and iron. Brazil provides 84 percent of U.S. imports of niobium, with the rest coming from Canada (12 percent) and Germany (2 percent). The United States has approximately 150,000 tons of niobium resources in identified deposits, all of which were considered not to be economical at 2012 prices for niobium. The amount of niobium recycled is not available, but it may be as much as 20 percent of apparent consumption.

Other materials can substitute for niobium, but higher costs or loss in performance may result. The list of substitutes is as follows.

- Molybdenum and vanadium, as alloying elements in high-strength, low-alloy steels
- Tantalum and titanium, as alloying elements in stainless and high-strength steels
- Ceramics, molybdenum, tantalum, and tungsten in high-temperature applications

Estimated Demand

Companies in the United States produced niobium-containing materials from imported niobium minerals, oxides, and ferroniobium. Niobium was consumed mostly in the form of ferroniobium by the steel industry and as niobium alloys and metal by the aerospace industry. Major end-use distribution of reported niobium consumption is as follows: steels, 79 percent, and superalloys, 21 percent. In 2012, the estimated value of niobium consumption was $487 million and was expected to be about $500 million in 2013 based on imports.

Supply Forecast

2014 USGS Minerals and Commodity Summary estimates the import dependence to be the same in 2013 as in 2012, where Brazil is the leading niobium supplier. U.S. niobium apparent consumption (measured in contained niobium) in 2012 was 9,160 metric tons, 12 percent more than that of 2011. World resources of niobium are more than adequate to supply projected needs. Most of the world’s identified resources of niobium occur mainly as pyrochlore in carbonatite (igneous rocks that contain more than 50 percent by volume carbonate minerals) deposits and are outside the United States.

Nitrocellulose

Description	Highly flammable, white, granular polyester resin. Propellant-grade nitrocellulose (NC), used by DoD, has a nitrogen content greater than 12.2 percent. Industrial grade has 10.8 percent to 12.2 percent nitrogen.	
Applications	Propellant grade is used in larger artillery as well as small- and medium-caliber weapons for military, civilian (sport and hunting), and law enforcement purposes. Industrial grade used in wood coatings, inks, and adhesives.	
Impact during a National Emergency	**Defense**	This smokeless propellant has no substitutes for use in ammunition for handheld weapons used by military personal and a variety of larger artillery weapons.
	Essential Civilian	No domestic supply of industrial-grade NC.
Shortfall	**Possible**	Insufficient data available for modeling through the NDS Program sizing module.
Supply Risks	**Single Domestic Producer**	Only one production facility in North America. The sole producer also has the only acid contractor facility that can produce the nitric and sulfuric acid grades required for NC production.
Current and Recommended Action	Continue close monitoring and collaboration within DoD.	

Nitrogen Tetroxide

Description	Nitrogen tetroxide (N_2O_4) is a powerful oxidizer used in liquid bipropellants. It is also known as NTO, dinitrogen tetroxide, and nitrogen peroxide with the propellant grade commonly referred to as a mixed oxide of nitrogen (MON).	
Applications	Nitrogen tetroxide can be used for powerful nitrification reactions in the pharmaceutical and chemical industries. Its primary use is in space exploration vehicles and defense applications.	
Impact during a National Emergency	**Defense**	Many defense applications now use substitutes for nitrogen tetroxide, but those that still use it tend to be space applications where substitution is difficult due to lack of oxygen in space.
	Essential Civilian	Used for commercial satellites but otherwise generally substitutable.
Shortfall	**Possible**	Insufficient data available for modeling through the NDS Program sizing module.
Supply Risks	**Single Domestic Producer**	One domestic producer has a contract to supply N_2O_4 for the DoD and the commercial satellite industry.
Recommended Action	Continue monitoring efforts and collaboration within DoD.	

Palladium

Description	Palladium (Pd) is a rare, silvery-white metal belonging to a class of metals known as the platinum group metals (PGMs). It is a good catalyst and has a unique ability to absorb hydrogen at up to 900 times its own volume	
Applications	Key applications: automotive catalysts, circuit boards for the electrical sector, chemicals, dental, and jewelry.	
Impact during a National Emergency	**Defense**	Known uses include circuit boards; brazing and soldering in aerospace applications. Limited quantitative information.
	Essential Civilian	Mainly limited to the automotive industry which is the biggest palladium demand sector. Substitution and recycling may be practiced by industry in case of national emergency.
Shortfall	**No**	Per 2015 NDS Program Report.
Supply Risk	**Limited Foreign Reliance**	The United States has two operational mines in Montana. Russia is world's largest supplier of palladium, accounting for 40 percent of global supply and presents possible supply risk due to sanctions stemming from the annexation of Crimea in March 2014 and continued support for pro-Russian separatists in Ukraine. South Africa is also a large producer and presents supply risk due to a protracted labor strike and high costs.
Recommended Actions	Continue monitoring efforts.	

Estimated Demand

According to PGM refiner Johnson Matthey, gross palladium demand (before recycling) totaled 9.63 million ounces in 2013, marking a slight slowdown from 2012 levels. Despite the drop in total palladium usage, demand in the automobile sector increased from 6.705 million ounces in 2012 to 6.97 million ounces in 2013 because of strong production of gasoline-based vehicles in the United States and China. Other than the investment segment, which saw a dramatic drop from an inflow of 475,000 ounces in 2012 to just 75,000 ounces in 2013, the remaining applications were basically flat to down from 2012 to 2013. Recycling is a big factor in the palladium market. In 2013, a total of 2.46 million ounces were recovered from the waste stream including 1.86 million ounces from spent autocatalysts, 420,000 ounces from the electrical sector, and 180,000 ounces from the jewelry segment. Subtracting recycling from gross demand, net demand for palladium totaled 7.17 million ounces in 2013, down from 7.68 million ounces in 2012.

Industry stakeholders and financial analysts are bullish on palladium in 2014 because of continued strong growth in the gasoline-based auto segment and strong investment inflows from the newly issued ETF (electronically traded fund) from Absa Capital, a unit of Barclays. HSBC Securities, for example, forecasts net palladium demand to total 7.55 million ounces in 2014, attributed, in part, to Absa's planned acquisition of 150,000 ounces of the metal to start its ETF.

Supply Forecast

World palladium supply totaled 6.43 million ounces in 2013, representing a decline of 100,000 ounces from the 2012 figure. As mentioned above, Russia is the world's largest producer of palladium. Russian palladium production comes from primary production and sales from the country's stockpile. In 2010, Russia's stockpile sales topped an estimated 1 million ounces (actual figures are a state secret). Russia's primary palladium production averages about 2.7 million ounces annually. South Africa is the world's second largest supplier of palladium with production totaling 2.35 million ounces in 2013, down from a 2012 peak of 2.64 million ounces. Production of PGMs in South Africa has been negatively affected by the labor strike that began in January 2014 over minimum wages and other conditions. As a result, palladium losses totaled 125,000 ounces in the first 2 months of 2014.

With the strike ending in June, world palladium production is expected to total about 6.5 million ounces this year. Stillwater Mining expects to produce approximately 525,000 ounces of platinum and palladium (combined) in 2014 following the expansion of the company's two mines in Montana. Russian palladium production is not expected to be widely affected in the medium term (though there might be short-term disruption) since Russia can always divert sales to China where palladium demand is expected to grow strongly. Russia already accounts for 30 percent of China's palladium imports.

Platinum

Description	Platinum (Pt) is a dense, malleable, ductile, highly unreactive, precious, gray-white transition metal belonging to a class of metals known as the platinum group metals (PGMs). The metal has excellent corrosion resistance, is stable at high temperatures, and has stable electrical properties. It does not oxidize at any temperature, although it is corroded by halogens, cyanides, sulfur, and caustic alkalis.	
Applications	Automotive catalysts (~40 percent of demand), chemical industry, electrical, glass production, jewelry, petroleum refining, and medical. Defense applications include aircraft turbine blades and coatings and engine seals and gaskets.	
Impact during a National Emergency	**Defense**	None known.
	Essential Civilian	Likely limited to automotive and petroleum refining sectors, which would be somewhat offset by extensive recycling.
Shortfall	**No**	Per 2015 NDS Program Report.
Supply Risk	**Moderate**	South Africa accounts for over 70 percent of global platinum production. Political, infrastructural, and labor issues have threatened its supply in recent years. A 5 month labor strike in South Africa in 2014 curtailed production at the country's three largest producers. North America produced 315,000 troy ounces of platinum in 2013.
Current Actions	The Defense Logistics Agency Strategic Materials is in the process of disposing of its 8,380 troy ounces of platinum.	
Recommended Actions	Continue monitoring efforts.	

Estimated Demand

Global gross (before recycling) demand for platinum totaled 8.42 million troy ounces in 2013, up from 8.030 million troy ounces in 2012. Autocatalysts and jewelry accounted for the majority of usage at 3.125 million troy ounces and 2.740 million troy ounces, respectively, in 2013. A rebound in the industrial sector (chemical, electrical, and glass), strong investment demand, and stable global auto sales drove growth in platinum demand in 2013. While consumption in the jewelry segment was down slightly from 2012 levels, it remained elevated compared to the 2010 trough when platinum consumption in this end use totaled 2.42 million troy ounces. An estimated 2.075 million troy ounces of platinum was recycled in 2013, the majority of which came from recycled autocatalysts and jewelry. This reduced gross demand to 6.345 million troy ounces, which implied an inventory reduction of 605,000 troy ounces. According to the USGS, U.S. platinum consumption totaled approximately 33,000 kilograms in 2013, which was equivalent to 1.06 million troy ounces. Defense demand for platinum is currently unknown.

Supply Forecast

Global platinum supply totaled 5.74 million troy ounces in 2013, up from 5.65 million troy ounces in 2012. Production in South Africa, at 4.12 million troy ounces, totaled 71 percent of global output in 2013. Russia was a distant second at 780,000 troy ounces, while Zimbabwe came in third at 400,000 ounces. As mentioned previously, North America produced 315,000 troy ounces of platinum in 2013 at a mine in Montana and at several locations throughout Ontario.

Global platinum supply is expected to advance slowly over the next several years. High costs, labor strikes, and political unrest are expected to translate into mine closures in the South African industry. This will be partially offset by growth in North America, Russia, and Zimbabwe.

Polypropylene Fiber

Description	Engineered coextruded woven polypropylene fiber.	
Applications	Vehicle C-kit armor plating, luggage, sporting equipment, automotive racing.	
Impact during a National Emergency	**Defense**	May be used in future for vehicle armor applications.
	Essential Civilian	None.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risks	**Foreign Reliance and Domestic Single Point of Failure**	One type of this fiber is being evaluated for future defense applications. All production is from one domestic firm, and raw material supplier is foreign. No current domestic suppliers for polypropylene tape (a precursor).
Recommended Action	Monitor to see if this material is used in future contracts for vehicle armor. This material was added to the Watch List as a result of an Army Research Laboratory request.	

Supply Chain

This polypropylene fiber is a coextruded, woven polypropylene fiber made by a single U.S. manufacturer. Civilian applications include aerosplitters for NASCAR, a line of impact-resistant luggage made by a U.S. firm, certain protective gear for athletic use, and a line of high-end domestically manufactured canoes. Cut into thicker sheets, it can be used for ballistic armor applications. It may be considered by DoD for use in future ground vehicles. Intact polypropylene fiber has the capability to be melted back down to a resin for recycling, though no known efforts to do so exist. Ultra high molecular weight polyethylene (UHMWPE) fibers can be used as a substitute for ground vehicle armor applications; however, it is more expensive.

Quartz Crystal, Synthetic

Description	Cultured or synthetic quartz is a manufactured single-crystal quartz produced by a hydrothermal process and is used for its unique piezoelectric properties.	
Applications	Crystal oscillators within watches and clocks, signal stabilization with radio transmitters and receivers, sensor material in extremely sensitive scales, and in Global Positioning Systems (GPS).	
Impact during a National Emergency	**Defense**	Military radios, electronic warfare, guidance systems, radar, navigation (GPS).
	Essential Civilian	Radio communication, aviation electronics, computer-controlled industrial equipment.
Shortfall	**No**	Per 2015 NDS Program report.
Supply Risk	**Foreign Reliance, Single Point**	Cultured quartz is not domestically manufactured and is primarily produced in Asia. In addition, not all of the feed materials required to manufacture quartz are domestically available.
Recommended Action	Continue monitoring efforts.	

Supply Chain

Quartz is one of the most abundant minerals in the earth's crust. It occurs as sand, in various composite minerals, and as a single crystal. In single-crystal form, quartz is a piezoelectric material. Naturally occurring single-crystal quartz has been mined throughout the world as gem stones, and certain low-defect crystals (electronic grade) could be cut and precision ground into plates for use in electronics. Due to the high cost of natural electronics-grade quartz, cultured quartz manufacturing was developed in the 1960s. Cultured quartz was produced by several companies domestically. However, economic conditions transitioned manufacturing to Asia. Currently, the United States is fully dependent on imports of cultured quartz. Domestic capacity still exists but would require significant refurbishment to restart commercial-level production.

Estimated Demand

Cultured quartz's unique piezoelectric properties make it valuable in the production of extremely sensitive mass sensors and crystal oscillators used in defense radar and guidance systems, consumer electronics, and watches. According to the *Mineral Commodities Summaries 2014,* published by the United States Geological Survey (USGS), demand for cultured quartz is forecast to grow in line with the demand for consumer and defense electronics.

Supply Forecast

Cultured quartz is produced primarily in Asia and directly supports electronics manufacturing. The manufacturing capability to produce cultured quartz is anticipated to be sufficient to satisfy future demand. The global availability of the cultured quartz feedstock materials (i.e., lascas) and hydrofluoric acid required to produce cultured quartz is anticipated to be sufficient.

Rare Earth Elements

Please see Rare Earths Section at end of Appendix 6a.

Rhenium

Description	Rhenium (Re) is a very rare metal that is also one of the densest elements. It generally occurs with molybdenum ores. Common forms include metal and alloys, ammonium perrhenate, and catalyst pellets.	
Applications	Used in high-temperature alloys including superalloys used in air transport and land power generation turbine engines; catalysts in petroleum refineries; filament wire in vacuum electronics and analytical instruments and thermocouples.	
Impact during a National Emergency	**Defense**	Certain defense applications cannot use substitutes for rhenium and are dependent on a reliable supply.
	Essential Civilian	The United States is the world's primary builder of turbine engines and is therefore strongly dependent on the rhenium supply. Limited substitution, recycling, and increased efficiency of use may help in a national emergency.
Shortfall	**No**	Per 2015 NDS Program report.
Supply Risk	**Small Unstable Market/Foreign Dominator**	The small quantities used can lead to single points of failure all along the supply chain. Limited domestic production (mainly catalysis) with high foreign reliance (Chile, Kazakhstan, Poland).
Current Actions	Title III is providing support for tungsten-rhenium wire production for defense electronics. The Defense Logistics Agency Strategic Materials is working with Title III.	
Recommended Actions	Continue monitoring efforts.	

Supply Chain

Rhenium is one of the rarest elements in the Earth's crust. It has the third highest melting point of any metal and is one of the densest elements. It is used, in small quantities, to improve the high-temperature characteristics of nickel, tungsten, and other alloys. It is used as a refractory in crucibles and similar applications. Rhenium is also used in catalysts used for petroleum refining. Rhenium is not mined as concentrated ore but is recovered as a by-product of molybdenum roasting. Molybdenum itself is mined as a by-product of copper mining. Chile is the world's largest rhenium producer, with large copper and molybdenum deposits. One domestic company recovers rhenium; the product is used primarily for catalysts. Rhenium is also produced in Kazakhstan, Uzbekistan, and recently, in Poland. Rhenium is often traded as ammonium perrhenate, which can be used in catalysts or can be oxidized to produce metal pellets or similar forms.

Several specialty firms and the major aircraft engine producers add rhenium products into superalloys used in turbine engines. A number of processors recover rhenium from scrap superalloys; rhenium is also reused through direct recycling of superalloy parts. Smaller amounts of rhenium are used in tungsten-rhenium wire for a variety of high-temperature electric filament applications, including radar and electronic warfare systems. The high cost of rhenium discourages its use, and efforts are under way to find alternatives for certain applications. The limited market for rhenium makes it susceptible to disruptions within the supply chain.

Estimated Demand

Most rhenium is consumed in turbine engine superalloys and in petroleum-refining catalysts. The aircraft and petroleum industries are stable or slowly growing industries. The number of natural gas turbine engines used to produce electricity is growing. The 2013 USGS Commodity Summary estimated apparent consumption of rhenium in 2012 as 44,000 kg. Of this, 70 percent is likely used in superalloys and 20 percent in catalyst applications.

Supply Forecast

The cost and scarcity of rhenium encourage its recycling, and the secondary market is robust. Chile continues to roast molybdenum ore from various locations. Production in Kazakhstan has fallen, roughly at the same time as a facility began operation in Poland. The 2013 USGS Commodity Summary estimated imported rhenium for consumption in 2012 as 34,000 kg, with 89 percent of metal forms from Chile and 29 percent of ammonium perrhenate from Kazakhstan.

S-glass

<table>
<tr><td>Description</td><td colspan="2">S-glass is a cost-effective composite glass fiber that offers high tensile and compressive strength, high-temperature resistance, and improved impact resistance. S-glass fiber has occasionally been combined with ballistic fibers when structural properties such as durability or limited back face deformation during impact are important.</td></tr>
<tr><td>Applications</td><td colspan="2">Defense – body armor, hard composite armor for vehicles and naval vessels.

Commercial – Aircraft cargo liners, cockpit door armor, flooring, fuel tanks, and structural parts; helicopter blades; construction materials; automotive mufflers and timing belts; printed circuit boards; electrical insulation; safety fabrics; pressure vessels; stove insulation; sporting equipment.</td></tr>
<tr><td rowspan="2">Impact during a National Emergency</td><td>Defense</td><td>A shortage of supply would impact the supply of defense articles for major DoD vehicle programs and naval ship programs. Heavier-weight or high-cost materials could be used in place of S-glass.</td></tr>
<tr><td>Essential Civilian</td><td>Limited; substitute materials could be used for fiberglass.</td></tr>
<tr><td>Shortfall</td><td>No</td><td>Per the 2015 NDS Program Study.</td></tr>
<tr><td>Supply Risks</td><td>Demand Surge</td><td>A sudden increase in demand during a national emergency could cause a supply shortage, as seen during past conflicts. Lesser performing substitute materials have been used in the past, such as basalt fiber, E-glass, and R-glass. Higher weight or higher cost materials such as steel, aramid-fibers, or polyethylene fibers are substitutes for vehicle armor applications.</td></tr>
<tr><td>Current Activity</td><td colspan="2">Two types of proprietary fibers have been qualified to Army performance specifications for use in DoD armor applications: MIL-DTL-64154B.</td></tr>
<tr><td>Recommended Action</td><td colspan="2">Monitor supply chain for a decrease in domestic production capacity because of declining defense demand over the last six years.</td></tr>
</table>

Silicon Carbide

<table>
<tr><td>Description</td><td colspan="2">Silicon carbide (SiC) is a synthetic material and is mass produced by a process of heating sand (SiO_2) in the presence of excess carbon in an electric furnace at a high temperature, between 1600ºC and 2700ºC. Silicon carbide occurs in nature as well, as an extremely rare mineral, moissanite.</td></tr>
<tr><td>Applications</td><td colspan="2">Used as a high-grade abrasive in various industrial applications, such as metal finishing, cutting and polishing. Also used in motor vehicle parts (brake discs, clutch and diesel particulate filters), broadcast and wireless communications equipment, electronic applications in high-temperature and high-voltage devices, LEDs, radio detectors, and body armor.</td></tr>
<tr><td rowspan="2">Impact during a National Emergency</td><td>Defense</td><td>Limited. Boron carbide could be used as an alternate material for body armor. Potential supply interruption if large (surge) amounts of body armor were required. Fused aluminum oxide is a very good substitute for SiC in abrasives.

Overall consumption of SiC for electronics in military applications is quite low (~1 percent of total demand) and could be substituted in conventional microwave monolithic integrated circuit (MMIC) by III–V materials such as gallium arsenide (GaAs) and indium phosphide (InP), although the latter substitution would be at an increased cost.</td></tr>
<tr><td>Essential Civilian</td><td>Limited. High-purity aluminum oxide and abrasive diamond could be used to substitute for 25 percent of the total demand for SiC in abrasive products in the United States. Organic/metal composites and cast iron could be used to substitute for the entire demand for SiC in motor vehicle parts.</td></tr>
<tr><td>Shortfall</td><td>No</td><td>Per the 2015 NDS Program Study.</td></tr>
<tr><td>Supply Risks</td><td>Foreign Reliance</td><td>Heavy foreign reliance on large producers – Russia, Japan, and China. Smaller producers are Canada, Mexico, and Peru.</td></tr>
<tr><td>Recommend Action</td><td colspan="2">Keep on the NDS Program Watch List.</td></tr>
</table>

Supply Chain

Russia, China, Brazil, Norway, and Japan were the major producers of SiC in 2011. There was only one major company that produced abrasive-grade SiC in the United States during 2012. A second company also produces a small quantity of SiC but for use in heat-resistant products rather than abrasives. Silicon carbide is traded in two forms: crude and refined. For 2013, net import sources of SiC originated from China (60 percent), South Africa (10 percent), the Netherlands (5 percent), Brazil (5 percent), Russia (5 percent), and others (15 percent). The net import reliance for SiC was close to 80 percent.

With new technological trends that require decreased use of abrasive products, improvement in economic conditions, and an increase in manufacturing activities in the aerospace, automotive, furniture, housing, and steel industries, the demand for SiC should stay constant for the next several years.

Production in the United States is likely to remain low for the next few years, and the overall world capacity, especially from China, looks to increase. The availability of low-cost products from China could lead to a decrease in domestic output.

As of 2012 data, an estimated 5 percent of total SiC is recycled.

Silicon Carbide Fiber, Multifilament

Description	Multifilament SiC fibers are synthetic materials used to reinforce metal, ceramic, and polymer matrix composites. They have excellent strength and elasticity properties and retain these properties at high temperatures.	
Applications	Mainly military applications including aerospace and missile defense.	
Impact during a National Emergency	**Defense**	Significant. There are limited substitution options for SiC fibers in most defense applications.
	Essential Civilian	Limited
Shortfall	**Yes**	Amount withheld.
Supply Risk	**Complete Foreign Reliance**	No domestic production. See Proprietary appendix.
Recommended Action	Acquire for NDS Program stockpile. Amount and projected cost withheld (proprietary).	

Silicon Carbide Wafers

Description	Substrates for high-voltage, high-frequency, high-power, and high-temperature semiconductor devices. Silicon carbide devices offer significant size, weight, and power advantages over alternative devices, in addition to performance advantages (e.g., higher frequency and temperature).	
Applications	Civilian – electric vehicles, wind turbines, power inverters for solar cell arrays, and industrial and commercial power supply. Military – Applications include aircraft carrier power systems, electronic warfare, air and missile defense, and advanced radar systems such as early warning aircraft, electronically steered array, and three-dimensional expeditionary long-range radar.	
Impact during a National Emergency	**Defense**	Limited. There is plenty of domestic production capacity.
	Essential Civilian	Limited. There is plenty of domestic production capacity.
Shortfall	**No**	Per the 2015 NDS Program Study.
Recommended Action	Continue monitoring efforts.	

Supply Chain

Silicon carbide wafers are produced by vertically integrated semiconductor manufacturers. The United States is the industry leader. Manufacturers start the production process by purchasing pure silicon and pure carbon. The carbon can be procured domestically. It is believed that the silicon can be purchased domestically as well, but verification is under way. Producers heat the silicon and carbon in a crucible to create SiC. Shape preforms are grown from the SiC using a vaporization process. The preforms are cut into wafers. Downstream device fabrication is often done in-house, and if not, there is plenty of domestic capability.

Strontium

Description	Strontium (Sr) is an alkaline earth metal. Due to its highly reactive nature, strontium is not present in the metallic form but in minerals, predominantly celestite ($SrSO_4$, 43.88 percent content).	
Applications	In civilian applications, strontium compounds are mostly consumed by the ceramic glass industry in producing cathode ray tubes (CRT), using about 75 percent of the world's production of strontium. Other minor applications for civilian use include permanent strontium ferrite magnets, metallurgical applications (added to aluminum alloys for aerospace and automotive industries and used to remove lead impurities during the electrolytic production of zinc), and additives to paints to prevent corrosion. Recently, it appears strontium has been used in drilling fluids in the oil and natural gas sectors. Defense applications are primarily in the pyrotechnics industry (e.g., signal flares), which in combination with this use in civilian applications consume 5 percent of the world's production.	
Impact during a National Emergency	**Defense**	Significant. Substitution is challenging for pyrotechnic applications as it is very difficult to obtain the same brilliance and visibility by any other material.
	Essential Civilian	Modest. Substitution of barium is possible in ferrite ceramic magnets but would degrade the quality, which would affect the maximum operating temperature threshold for the magnet composites. Sodium is an adequate substitute for strontium in master alloys, mainly as an additive to aluminum-silicon alloys.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risks	**Foreign Reliance**	No domestic production. Heavy reliance on large foreign producers—China, Mexico, Germany, and Spain. Smaller producers are Argentina, Iran, Morocco, and Turkey.
Recommended Action	Continue monitoring efforts.	

Supply Chain

China, Spain, and Mexico are the major suppliers of celestite (the most commonly found strontium mineral), representing a total of 96 percent of the world production in 2011. Turkey was once a leading celestite producer but has experienced significant declines in production in recent years. Turkey had no celestite production in 2009 and 2010, but production resumed in 2011. Germany has no production of celestite or other strontium compounds but has a refining capacity of 55,000 MT. Imported strontium (minerals and compounds) originated from Mexico (78 percent), Germany (11 percent), China (9 percent), and other (2 percent). Many industries consume strontium compounds, including the glass, ceramic, and pyrotechnics industries. Besides being used as strontium carbonate alone, it is converted into strontium chloride, strontium hydroxide, or strontium nitrate. Ceramic ferrite magnets are relied upon for small direct current motors including speakers, toys, windshield wipers, and other electronics. Strontium nitrate is used most often as a coloring agent in pyrotechnic applications including civilian and military flares, fireworks, and tracer ammunition. The United States currently has two concerted programs for strontium, which would allow production to ramp up rapidly if needed.

Production shifts to Asia mean that imports to and exports from the United States are not consistent from year to year, and the estimated US demand for strontium is very difficult to calculate. Also, the displacement of CRTs by other display techniques for television sets is affecting strontium's overall consumption. Future demand for strontium carbonate may be higher than in previous years because of improvements in the economy, increased use in industries such as glass, ceramics, and pyrotechnics, and the increased demand for ferrite magnets. With improvements being made in advanced applications, consumption of strontium in new end uses may increase as well.

Sulfur Hexafluoride

Description	Sulfur hexafluoride (SF_6) is a gas with high dielectric strength, very good thermal and chemical stability, and good arc quenching ability. SF_6 has high global warming potential. As a result, its production and use could decline substantially in the coming years.	
Applications	Defense – The DoD uses SF_6 as a dielectric at overseas and continental military bases and in various military platforms. Civilian – SF_6 is often used as an insulator in high-voltage power applications such as switchgear, wave guides, coaxial cables, X-ray tubes, and transformers. SF_6 is also used in the semiconductor industry as an etching or cleaning gas. In addition, there are some medical uses such as a contrast agent in ultrasound imaging.	
Impact during a National Emergency	Uncertain. Investigation of substitutes and alternate technologies is under way.	
Shortfall	**Possible**	Work is currently under way to evaluate and quantify a potential shortfall.
Supply Risk	**Complete Foreign Reliance, Foreign Dominator**	The US produces no SF_6. It is believed that China produces over 50 percent of the world supply.
Recommended Action	Continue monitoring efforts and efforts for shortfall analysis.	

Supply Chain

The supply chain begins with acid-grade fluorspar, the primary producers of which are China (55 percent) and Mexico (20 percent). The United States does not produce acid-grade fluorspar and imports it primarily from Mexico. Acid-grade fluorspar reacts with sulfuric acid to produce hydrofluoric acid (HF), which is made in the United States by two large chemical companies. The HF is then treated with sulfur to produce SF_6. The United States does not produce SF_6, so it is imported and then purified before end-use integration.

Substitutes may not be available for many military applications. In addition, production may decline substantially due to concerns over global warming. Furthermore, there is no current U.S. production of SF_6, and global supply is concentrated in China. Further analysis is under way.

Tantalum

Description	Tantalum (Ta) is a rare, hard, gray, lustrous transition metal that is highly corrosion resistant.	
Applications	Tantalum is used in capacitors in electronics, chemical processing equipment, heat exchangers, corrosion-resistant fasteners (e.g., screws), anti-lock brake systems, airbag activation systems and engine management modules, and high-temperature aerospace engine parts.	
Impact during a National Emergency	**Defense**	Highest concern for tantalum in nickel superalloys for high-temperature sections of jet engines and capacitors for DoD military specification (MILSPEC) and U.S. space applications. Shaped charge and explosively formed penetrator liners, missile systems, ignition systems, night vision goggles, global positioning systems.
	Essential Civilian	Some industrial substitution is possible, but usually with less effectiveness: niobium in carbides; aluminum and ceramics in electronic capacitors; and hafnium, iridium, molybdenum, rhenium, and tungsten in high-temperature applications.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risk	**Foreign Reliance: Conflict Mineral**	No domestic mining; some recycling at industrial level. The mining of tantalum primarily occurs in central Africa and Brazil. Material sourced from central Africa must be certified conflict free.
Current Action	Current stockpile contains 3,777 lbs tantalum, equivalent tantalum carbide powder, and 190 lbs tantalum metal scrap.	
Recommended Action	Material requested for acquisition.	

Supply Chain

Tantalum is estimated to make up about 0.7 ppm of the Earth's crust by weight. Tantalum, always together with the chemically similar niobium, occurs in the minerals tantalite, columbite, and coltan (a mix of columbite and tantalite). The mining of tantalum primarily occurs in central Africa, Brazil, and Australia.

The United States has about 1,500 tons of tantalum resources in identified deposits, all of which are considered uneconomical at current prices. Despite the lack of domestic tantalum mining, the

United States has robust downstream processing capabilities. Most of the identified resources of tantalum are in the DRC, Australia, and Brazil.

Tantalum can be substituted by other materials, but usually with a loss in performance. The list of substitutes is as follows: niobium in carbides; aluminum and ceramics in electronic capacitors; glass, niobium, platinum, titanium, and zirconium in corrosion-resistant equipment; and hafnium, iridium, molybdenum, niobium, rhenium, and tungsten in high-temperature applications.

The tantalum industry must report supply data as per the relatively new Dodd-Frank conflict minerals legislation. Dodd-Frank requires companies to report annually to the U.S. Securities and Exchange Commission the use of conflict minerals from the DRC or nine adjoining countries. The Tantalum-Niobium International Study Center (TIC) collects supply data from miners and traders of primary metal as well as receipts from smelters. Theoretically, the Dodd-Frank reporting data, the TIC data, and the USGS data should have a strong correlation. Discrepancies between the data sources could be a result of inventory drawdowns from material purchased prior to Dodd-Frank reporting requirements, incomplete/inaccurate reporting, or the result of illegal activities. Additionally, reporting is further complicated by the fact that scrap material is not subject to Dodd-Frank reporting. The Defense Logistics Agency Strategic Materials will be comparing tantalum supply data sources before the next reporting cycle.

Some representatives from the tantalum industry have expressed that the push for material certified conflict free could create a two-tiered market with buyers willing to pay a premium for certified material. There is also concern that regulations will adversely impact legitimate mining operations in the region. The Defense Logistics Agency Strategic Materials will continue to closely monitor the tantalum supply chain.

Estimated Demand

Tantalum was consumed mostly in the form of alloys, compounds, fabricated forms, ingot, and metal powder. Tantalum capacitors were estimated to account for more than 60 percent of tantalum use. Major end uses for tantalum capacitors include automotive electronics, pagers, personal computers, and portable telephones. The value of tantalum consumed in 2012 was estimated at about $285 million and was expected to exceed $300 million in 2013, as measured by the value of imports. It was anticipated that as the global economy recovered, so too would the demand for tantalum. Tantalum demand was expected to increase 6 percent per year.

Supply Forecast

The 2014 USGS Minerals and Commodity Summaries estimate the apparent tantalum consumed in 2012 at 1,010 MT and was expected to exceed 1,110 MT in 2013. Tantalum was consumed mostly in the form of alloys, compounds, fabricated forms, ingot, and metal powder. Tantalum waste and scrap was the leading imported tantalum material, accounting for about 51 percent of tantalum imports.

Tellurium

Description	Tellurium (Te) is a mildly toxic semiconductor, mainly used in alloyed form.	
Applications	Tellurium compounds are mostly consumed in the production of various alloys used in solar cells and thermoelectric devices. Tellurium is also used in the manufacture of semiconductors, in metallurgy, and in the production of rubber. For defense applications, thermal imaging devices such as short and mid-wave IR sensors, thermoelectric coolers for IR detectors, integrated circuits, laser diodes, and medical instrumentation are the main consumption areas.	
Impact during a National Emergency	**Defense**	Modest. Silicon is a good substitute in thermal imaging devices and navigation systems. However, there are currently no substitutes for tellurium in thermoelectric devices.
	Essential Civilian	Limited. Bismuth could be used as a substitute for metallurgy for ferrous products, and lead could be used as a substitute for nonferrous products. Both of these substitutes in place of tellurium would result in minor loss in product properties.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risks	**Foreign Reliance**	Sole current U.S. refiner is planning to move its facility. Domestic capacity, currently idle, could be ramped up in 4 to 12 months. Canada and China are the largest sources of imports.
Recommended Action	Continue monitoring efforts.	

Supply Chain

Tellurium is recovered as a by-product of nonferrous metal mining, primarily from the anode slimes produced during the electrolytic refining of copper. The concentration of tellurium in these slimes averages 2 percent by weight. A small amount of tellurium is also recovered from industrial scrap, like photoreceptors used in older plain paper copiers.

Russia, China and Japan were the major producers of tellurium in 2011. In recent years, major sources of imports were Canada, China, and to a lesser extent the Philippines. In the United States, the single source of production for refined tellurium has decided to move its production lines to an unused facility in Mexico in the near future. No known U.S. concerted program exists currently, though tellurium production capacity could be instituted since tellurium is refined in the same facilities as copper.

Solar cell production, and associated demand for tellurium, is expected to decrease for the next few years because of the high availability of solar cells in the market. Technological advances will likely increase the efficiency of tellurium in thermoelectrics, solar cells, etc., which would further reduce consumption and bring down demand. The future supply of tellurium greatly depends on the future production of copper and other metals such as gold, lead, nickel, zinc, etc. Global production of copper is on an uptrend, which bodes well for tellurium production. An increase in recycling efforts would also lead to an increase in tellurium supply.

Tin

<table>
<tr><td>Description</td><td colspan="2">Tin (Sn) is a corrosion-resistant, malleable, and non-toxic metal.</td></tr>
<tr><td>Applications</td><td colspan="2">Used in tinplating (e.g., food containers), bronze and brass alloys, solders, and as a chemical compound in a variety of applications. In high tech, it is used in LCD TVs and touch screens in the form of indium tin oxide.</td></tr>
<tr><td rowspan="2">Impact during a National Emergency</td><td>Defense</td><td>As an alloy, it is used in bearings.</td></tr>
<tr><td>Essential Civilian</td><td>Highly recycled and substitutable in food packaging and solders. However, indium tin oxide is a critical application, and its use is growing.</td></tr>
<tr><td>Shortfall</td><td>No</td><td>Per 2015 NDS Program study.</td></tr>
<tr><td>Supply Risk</td><td>Limited Foreign Reliance</td><td>No U.S. mining of tin due to poor quality of resources, but recycling does provide domestic supply. Import reliance is mainly from South America and Southeast Asia.</td></tr>
<tr><td>Current Action</td><td colspan="2">Defense National Stockpile includes 4020 MT as of FY 2013.
No plans to sell (Goal 4020 MT).</td></tr>
<tr><td>Recommended Action</td><td colspan="2">Maintain current inventory and continue monitoring efforts.</td></tr>
</table>

Supply Chain

The United States is highly reliant on tin imports to satisfy domestic demand. Imports come primarily from South America and Southeast Asia and include Peru (47 percent), Bolivia (17 percent), Indonesia (13 percent), Malaysia (9 percent), and other countries (14 percent).

Tin is mined throughout the world and may be a by-product of zinc, silver, tantalum, or tungsten mining. Tin is typically traded on the London Metal Exchange (LME) and is warehoused throughout Europe, United States, and Asia. Tin prices increased approximately +7 percent in 2012–2013 according to the World Bank commodity price report. Preliminary data from the World Bureau of Metal Statistics 2013–2014 indicate tin prices increased +11 percent.

Estimated Demand

In 2013, U.S. tin consumption increased +7 percent (from 27,740 to 29,760 MT). In the previous decade, U.S. tin consumption has generally declined from 2005–2012, with the exception of 2008–2009. The +11 percent increase in 2008–2009 may be attributed to the economic recovery. The 5 year forecast shows declining U.S. consumption; however, this forecast may be revised as more current 2014 economic data become available. The International Tin Research Institute (ITRI) optimistically forecasted +2 percent growth in worldwide tin consumption and is driven by the use of solder by the electronics sector.

Supply Forecast

Presently, there are no domestic producers of tin. The United States does have secondary production through tin recycling. It is fairly easy to recycle from automotive scrap and obsolete parts. The United States has both detinning plants and nonferrous metal processing plants that can process tin scrap. In 2012–2013, world tin production declined -4 percent. According to the USGS, world tin production has been steadily declining from 2005 (302,000 MT) through 2013 (230,000 MT). At this time, there is no evidence of supply disruptions; however, there are some areas of concern. The 5 year forecast indicates tin production may show low to zero growth, and less optimistically, a decline in production to 150,000 MT.

In 2014, Indonesia attempted to restructure their tin export market so more value-added tin products are exported rather than raw material. Indonesia ruled that tin ingots must be traded on the Indonesia Commodity and Derivatives Exchange before shipment. Currently, the LME processes most tin trading and sets the benchmark price. Indonesia is trying to wrestle tin trading away from LME in order to develop a domestically determined benchmark price and have greater control of the market. So far this policy has been unsuccessful, and the Indonesian government is adjusting rules as necessary in order to sustain their economy.

Tourmaline

Description	Tourmaline is a semiprecious mineral composed of boron-silicate crystal compounded with aluminum, iron, magnesium, sodium, lithium, or potassium. It is notable for its piezoelectric properties (produces an electrical response to a mechanical load) and functionality at high temperatures.	
Applications	Accelerometers used in aerospace and ballistics, sensors such as for shock/vibration monitoring, gemstones.	
Impact during a National Emergency	**Defense**	High-temperature, piezoelectric accelerometers and sensors require flawless or near-flawless natural tourmaline.
	Essential Civilian	Limited since alternatives to tourmaline exist for civilian applications.
Shortfall	**Possible**	Amount unknown.
Supply Risks	**Foreign Reliance**	Tourmaline is sourced in a few Latin American and African countries.
Recommended Action	Short term: Further study to consider need for stockpiling of tourmaline to support H-1 system requirements. Continue monitoring and collaboration within DoD. Long Term: Explore alternative sources such as U.S. mines and synthetic piezoelectric materials.	

Supply Chain

Tourmaline is a semiprecious mineral widely known for its esthetic properties and utilized in piezoelectric, high-temperature sensors. Structurally perfect tourmalines are in high demand by consumers and the defense industry.

Tourmaline deposits can be found throughout the world and are typically found in pegmatite (crystalline, igneous rocks.) Tourmaline mining is typically small scale and labor intensive. Commercial mining occurs in Brazil, Mozambique, Sri Lanka, and Tanzania. Tourmalines mines also operate in the United States. There are approximately ten artisanal mines operating in Maine, California, Colorado, and New York.

Aerospace turbine engines are the primary defense applications of tourmaline. H-1 helicopters utilize tourmaline accelerometers. The tourmaline must be flawless or near flawless. Tourmaline color is unimportant. Carat size requirements are unknown. Tourmaline accelerometers specifications are proprietary, so exact requirements are not yet available. Synthetic tourmaline cannot be used as a direct substitute in accelerometers. Properties such as high operating temperature and resonance are difficult or impossible to recreate.

The United States is almost completely reliant on tourmaline imports. Tourmalines typically enter the country as jewelry, cut gemstones, or semi-finished industrial goods such as sensors. Tourmaline import data are not separately available in a specific Harmonized Trade Code. They are embedded in broader categories like "jewelry of other materials" or "other measuring or checking instrument."

Tourmalines are bought and sold through agreements between manufactures, gem wholesalers, and mines. Tourmalines are not traded through commodity markets. Since transactions occur through private buyers and sellers, it is difficult to estimate market size and prices.

Preliminary analysis indicates retail and wholesale tourmaline prices are historically high. Prices depend on color, clarity, cut, and availability. Gemval.com, an online resource for retail prices, publishes a tourmaline price index. The annual average growth of the tourmaline price index increased +11 percent in 2005–2014. Average retail prices for tourmaline tripled in 2005–2014. Tourmaline wholesale prices range significantly, from $10 to $10,000 a carat.

Estimated Demand

Worldwide tourmaline consumption is primarily driven by jewelry consumer demand. Consumer and defense demand both favor higher quality tourmaline specimens. Tourmaline crystals used for defense applications require flawless or near-flawless structure. The crystal color is unimportant; however, black schorl tourmaline is most common. For consumer demand, better quality stones fetch higher prices. Tourmalines are ideal for jewelry due to their color range and sturdiness.

Several trade magazines indicate Chinese consumer demand surged in 2011. Preliminary analysis indicates Chinese demand will grow in step with consumer incomes. The Chinese jewelry manufacturing industry also contributes to total tourmaline demand. Defense Logistics Agency Strategic Materials is currently working with U.S. Naval Air Systems Command to determine defense demand.

Supply Forecast

World supply is difficult to estimate. Limited data are available for Brazil, Mozambique, and Tanzania. Preliminary analysis indicates constrained supply in the future. Oak Ridge National Laboratory noted Brazil tourmaline production is diminishing or nearing exhaustion. According to the USGS, Mozambique and Tanzania extracted 36 MT of tourmaline in 2011. In 2008–2011, Mozambique averaged 20 MT, while Tanzania averaged 8 MT. It is unclear whether Mozambique can sustain production output because of its inadequate infrastructure, difficult investment climate, and budget deficit.

Triamino-Trinitrobenzene and 1, 3, 5 Trichlorobenzene

Description	Trichlorobenzene (TCB) is used to produce triamino-trinitrobenzene (TATB) and TATB-based insensitive high explosive (IHE) molding powders, which are used to produce fuzes.	
Applications	Hardened penetration bombs, mortars, missiles, and other explosives.	
Impact during a National Emergency	**Defense**	Platforms are critical to Army, Navy, Marine, Air Force, and National Nuclear Security Administration (NNSA) capabilities.
	Essential Civilian	N/A
Shortfall	**Yes**	Per the NDS Program analysis.
Supply Risks	**Foreign Reliance**	TCB, the precursor chemical required to produce TATB, is only manufactured in India and China with no acceptable substitutes. However, the unstable chemical nature of TCB precludes long-term storage.
Current Activity	Acquisition approved for stockpiling in the FY 2014 NDAA. The Defense Logistics Agency Strategic Materials is collaborating with the DoD, Army, Navy, Air Force, and DoE NNSA to stockpile grades of TATB and TATB products.	
Recommended Action	Establish a combined stockpile inventory of TATB and five types of IHE molding powders, combined. The stockpile inventory will be established during a three year period from FY 2015 to FY 2017. Authority was requested in FY 2014 to initiate budget requests and develop acquisition vehicles.	

Supply Chain

TATB and TATB-based IHE molding powders are critical for conventional and nuclear weapons. The DoD and NNSA require TATB to be produced using the Benziger process, which requires TCB. TCB is foreign produced, environmentally unfriendly, and not suitable for long-term storage because of its chemical instability. TATB-based IHE molding powders are produced by combining TATB along with another high explosive such as HMX or RDX and a binder. These molding powders are used as booster/fuse explosives and as initiator explosives in a wide range of tactical and strategic munitions by the Army, Navy, Air Force, and DoE NNSA.

Estimated Demand

The DoD and DoE demand for IHE molding powders is expected to increase because of requirements to reconstitute depleted DoE and DoD inventories. Additionally, specialty commercial applications for TATB-based explosives within the oil, gas, and mining industry may resume in connection with increased domestic energy initiatives. U.S. requirements are currently met using the new Holston Facility (mentioned below). Typically, 1 lb of TCB yields the same mass of TATB. Depending on the molding powder type, TATB makes up 40–95 percent of the total consumption.

Supply Forecast

At present, no domestic manufacturing facilities produce the precursor chemical TCB. There is one domestic producer that is qualified to produce TATB for some of the IHE molding powders used by DoD. Global TCB production is only active in India and China principally due to the environmentally hazardous nature of the process and end products. Two domestic companies have proposed examining the local manufacture of TCB, with only one reporting any success; however, chemical processes and facilities have not been established and any domestically produced TCB materials will by exorbitantly expensive. A joint-service program was recently completed to reactivate TATB production lines domestically. This plant was recently qualified for TATB manufacture. However, the DoD and DoE will be solely reliant on foreign sources of supply for TCB for the foreseeable future. Regardless of TATB manufacturing capability, domestic fabrication of IHE materials will be rate limited and thus restricted by TCB supplies, which have limited storage properties because of inherent chemical instability.

Tungsten

Description	Tungsten (W) is a dense metal with the highest melting point of all metals. Tungsten carbide is an exceptionally hard dense substance.	
Applications	Tungsten metal is used in alloys intended for high-temperature operation, including superalloys and tool steels. Tungsten is used in high-temperature electrical filament applications. Tungsten carbide and metal alloys are used for ammunition. Tungsten carbide is used for high-wear surfaces in applications such as cutting tools.	
Impact during a National Emergency	**Defense**	High-temperature superalloys used in military turbine engines, tungsten filaments for electronics and lighting and armor-piercing ammunition are key defense uses. Some recycling may offset need for mined tungsten.
	Essential Civilian	In case of a National Emergency, reduction of exports of tungsten products and substitution by industry to other materials in civilian applications are possible.
Shortfall	**Yes**	There is a net shortfall of 4.12 million pounds W.
Supply Risks	**Single Domestic Point of Failure**	Single US mine and other possible single points of failure along supply chain. Most tungsten worldwide is mined and refined in China.
Current Activity	The National Defense Stockpile holds approximately 275,700 lbs of tungsten contained in tungsten metal powder and almost 26 million lbs of tungsten contained in ores and concentrates.	
Recommended Action	Prepare a supply chain analysis to detail tungsten shortfall.	

Supply Chain

The world's largest deposits of tungsten are found in China, and the market for both tungsten ores and processed tungsten products is dominated by China. About 85 percent of 2013 world mine production was from China. Historically, when political instability limited China's tungsten output, mines were exploited in other countries. Many of these mines closed as Chinese production was restored. Tungsten deposits exist in the U.S., but aside from the small Andrew Mine in California, are not being exploited. Tungsten concentrate continues to be mined in Canada and Russia. Tungsten concentrate is refined into ammonium paratungstate, tungsten powder, and tungsten metal and carbide forms.

Tungsten is extensively recycled. Tungsten carbide particles may be recovered from cutting tools and recycled directly into similar applications. Tungsten was one of the first elements added to steel alloys, and is especially used in high speed tool steel. Tungsten is one of the key elements added to nickel and cobalt based superalloys. Tungsten is recycled indirectly through the recycling of tool steel and superalloys, and may be recovered from tool steel and superalloy scrap. USGS Commodity Summary data indicates that about 60 percent of apparent domestic consumption in 2013 was met through the secondary market.

In addition to the tool steel and superalloy supply chains, tungsten is used directly by a number of industries. Filaments for incandescent light bulbs are made of tungsten, and tungsten or tungsten alloy filaments continue to be used in a variety of vacuum electronic systems including radar systems. Tungsten carbide or tungsten alloys are used in armor-piercing ammunition and in specialty applications such as welding rods, radiation shielding, and counterweights.

Estimated Demand

The 2014 USGS Commodity Summary apparent consumption of tungsten in all forms for 2013 was estimated to be 13,900 metric tons, of which 8,300 metric tons was produced in the secondary market. Sixty percent of tungsten is used in the tungsten carbide form, often with tungsten carbide particles embedded in a cobalt “cemented” matrix.

Supply Forecast

China is attempting to control its tungsten industry by concentrating it into larger firms and encouraging export of refined products through taxation of ores and concentrates. In the near term, Chinese exports of ammonium paratungstate and other refined products are likely to remain steady. Several other countries are expanding exports of ores and concentrates. The domestic and international secondary markets are well-developed, and recovery of both tungsten and useable alloys should continue.

Downstream producers, such as Global Tungsten Powders, are adapting to the declining demand for incandescent lighting filaments. This has impacted secondary applications of filaments, such as used in vacuum electronics. Downstream production of superalloys and tool steels, and of cutting tools based on tungsten carbide, should remain stable.

Ultra High Molecular Weight Polyethylene Fiber

Description	Ultra high molecular weight polyethylene (UHMWPE) fiber composites are used for lightweight armor applications (body-armor backing, vehicle armor, and helmets). Because of their high strength-to-weight ratio, they are an alternative to heavier armor materials. Military specification, MIL-DTL-32398, classifies three types of UHMWPE fiber systems that are qualified for DoD armor applications.	
Applications	Defense – U.S. body armor programs and vehicle armor programs. Commercial – Cordage, recreational/sport industry, and textile industry.	
Impact during a National Emergency	**Defense**	UHMWPE fiber composites allow for the lightest weight armors. When a surge in demand was seen during past conflicts, lesser performing and heavier materials were used as substitutions.
	Essential Civilian	Limited. Many substitutes are available.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risks	**Demand Surge**	A sudden increase in demand during a national emergency could cause a supply shortage, as seen during past conflicts.
Recommended Action	Monitor supply chain for a reduction in domestic capacity due to declining defense demand over the last six years.	

Supply Chain

There is available U.S. supply to meet current U.S. demand. Three companies produce these fibers, and these companies have a total of four facilities across the globe. One facility is in the Netherlands, and the other three are in two different states in the United States.

Vanadium

Description	Vanadium (V) is a soft, silvery gray, ductile, and malleable metal. The formation of an oxide layer stabilizes the metal against oxidation. Vanadium has good corrosion resistance to alkalis, sulfuric acid, hydrochloric acid, and salt waters. The element is found only in chemically combined forms in nature.	
Applications	Most vanadium is used as an additive to improve steels. Steel, specialty steel, catalysts, titanium-aluminum-vanadium alloys for jet engines, cladding, vanadium-gallium tape for superconducting magnets, and glass coatings are the principal applications for vanadium.	
Impact during a National Emergency	**Defense**	According to the USGS, there is currently no suitable substitute for vanadium in aerospace titanium alloys.
	Essential Civilian	There are several substitutes for vanadium-containing steels such as manganese, molybdenum, niobium, titanium, and tungsten. Nickel and platinum could replace vanadium compounds as catalysts in some chemical processes.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risk	**Foreign Reliance**	The United States is currently 100 percent import reliant on vanadium. However, two existing mines in the United States could potentially restart, and one new mine is currently under development.
Recommended Action	Continue monitoring efforts.	

Estimated Demand

According to the consulting firm Roskill, world vanadium consumption totaled 80,000 metric tons (contained V) in 2012, up from 73,000 metric tons in 2011. At approximately 27,000 metric tons, China was the world's leading consumer of vanadium owing to its large steel industry and the country's intensity of vanadium usage within steel. The second largest consuming region is Western Europe, with a consumption of 15,000 metric tons in 2012, up from 12,000 metric tons in 2011. North American consumption totaled 11,000 metric tons in 2012. According to the USGS, U.S. apparent consumption of vanadium (equal to production + imports – exports + stock changes) totaled 8,530 metric tons in 2012. U.S. vanadium imports totaled an estimated 9,353 metric tons in 2012, while exports totaled 1,144 metric tons. The United States produced only 272 metric tons of vanadium in 2012, so the balance of exports was from previously produced stocks. The United States' reliance on imported vanadium rose from 81 percent in 2009 to 97 percent in 2012 and is expected to reach 100 percent in 2013. The United States' main suppliers of ferrovanadium are Canada and the Czech Republic, whereas Russia and South Africa are its main suppliers of vanadium pentoxide.

As over 90 percent of vanadium is destined for the steel industry, growth in the use of vanadium will be largely a function of the development of the global steel sector, which, in turn, is dependent on the production of steel-intensive products such as automobiles, aviation, and major structures such as bridges, dams, and commercial buildings. As the trend in automobiles and aviation is toward lighter weight, the use of steel is expected to plateau and even drop off in the future. Thus, steel's main driver is expected to be infrastructure and commercial real estate. Therefore, growth in the use of vanadium in specialty alloys and high-strength, low-alloy steel will very much depend on future regulations regarding strength standards of steel in these end uses. On this front, China will be the principal driver as the country attempts to bring its building codes in line with the developed world and it continues to industrialize.

Supply Forecast

World vanadium production is estimated to have been nearly 74,000 metric tons (V) in 2012, of which nearly 40,000 metric tons (contained vanadium), or 52 percent of the total, was accounted for by China. All of the growth in vanadium production has been the result of co-production from the growth in steelmaking from vanadium-bearing titaniferous magnetite ores. Nearly two-thirds of all vanadium production was the result of co-production in 2012, up from a 50 percent share in 2006.

As mentioned, China has been responsible for nearly all of the growth in vanadium production over the past several years, with vanadium output growing from just 18,000 metric tons in 2006 to 40,000 metric tons in 2012. The United States ceased all vanadium mine production in 2013 when the country's sole vanadium co-product producer was acquired by another company that decided to focus its business on uranium production. According to the USGS, there are currently seven firms in the United States that produce vanadium products such as ferrovanadium, vanadium pentoxide, vanadium metal, and vanadium-bearing chemicals or specialty alloys through the processing of petroleum residues, spent catalysts, utility ash, or vanadium-bearing pig iron slash.

According to the USGS, there are currently nine vanadium projects at varying degrees of completion that could add a combined capacity of 54,000 metric tons of vanadium per year if all were to come to fruition. There are two mines in the United States that could be restarted with minimal investment. Finally, a new domestic project is in the development and permitting process for vanadium pentoxide production. In Canada, new supply is also coming online in the next 2 years.

Zinc

Description	Zinc (Zn) is a metal and is the 24th most abundant element in the earth and the 4th most common metal in use. Zinc is often used for its anti-corrosion properties. Zinc-coated steel is called galvanized steel.	
Applications	Motor vehicle parts, shipbuilding and repairing, and various fabricated metal products are the primary uses in civilian applications. For defense applications, high-grade zinc is used in galvanization for ship building, metal fabrication, alloys, and corrosion protection.	
Impact during a National Emergency	**Defense**	Limited. U.S. import reliance is small, and zinc can be substituted with various elements in chemical, electronic, and pigment uses. Substitutes for galvanized sheet include aluminum, plastics, and steel; for die casting materials, aluminum, magnesium, and plastics can be substituted. For corrosion protection, substitutes include aluminum alloy, cadmium, paint, and plastic coatings. Aluminum alloys substitute for brass.
	Essential Civilian	Limited. U.S. supply and substitutes are available.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risks	**None**	Much of the zinc consumed in the United States is produced domestically. Very low foreign reliance on large producers—China, Australia, and Peru. Smaller producers are Canada, Brazil, India, and Mexico.
Current Action	NDS Program currently holds zinc in inventory.	
Recommended Action	Release for sale of some of the metal currently held in reserve.	

The most common zinc ore is sphalerite (zinc blende), a zinc sulfide mineral. The largest mineable amounts are found in Australia, Asia, and the United States.

Pure zinc metal is produced by an extractive metallurgy process, which involves collecting zinc sulfide concentrates by a froth flotation process and then roasting them to produce zinc oxide. The zinc oxide is then reduced by either pyrometallurgy or electrowinning processing methods to produce zinc metal.

U.S. mine production during 2013 was roughly 750,000 MT; a few of the zinc-producing states are Alaska, Tennessee, Missouri, and Idaho. About 60 percent of the refined U.S. production of zinc comes from the secondary materials, such as galvanizing residues and crude zinc oxide from electric arc furnace dust. U.S. production of zinc could decline in the near future as one of the major domestic suppliers may transition to mining lower grade ore at the deposit. The United States has a good constant domestic supply of zinc as mining and refining capacities are very established and supply a significant portion of domestic demand. A single point of failure in the supply chain of zinc does not exist. The prime exports of zinc by the United States are ores and concentrate, while its primary import is refined zinc. The United States has one of the highest zinc reserves (10 million MT) in the world. World production capacity for zinc is comfortably above current production levels and also above projected demand levels.

The galvanization of steel accounts for the largest share of U.S. domestic consumption, and the demand for this use is fairly consistent.

Rare Earths

This section contains a general discussion of the rare earth elements and is followed by individual rare-earth-element exhibit tables. The rare earth elements are grouped together because of their similarities in both sourcing and material properties. As a result, rare earth elements are often mined and processed together, and many end up in similar end-use applications. However, the individual tables also show that there are differences that need to be considered.

Description	Rare earths are a family of 17 elements in the periodic table consisting of the lanthanide series (atomic numbers 57–70) plus scandium (Sc, atomic number 21) and yttrium (Y, atomic number 39). The lanthanide series is commonly split into two sub-categories, the "light" rare earths [lanthanum (La) and cerium (Ce) through samarium (Sm)] and the "heavy" rare earths [europium (Eu) through lutetium (Lu)]. Some analysts split the lanthanide series into three camps – light [La, Ce, praseodymium (Pr), and neodymium (Nd)], medium [Sm, Eu, and gadolinium (Gd)], and heavy [terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb)and Lu]. Promethium (Pm) is technically a rare earth but is radioactive, unstable, and extremely scarce, so it has very limited practical use. Rare-earth-containing ores such as bastnasite, monazite, xenotime, loparite, and ion adsorption clays (among others) are first mined, ground to a specific size, and then concentrated. The mixed rare earth concentrate can then be shipped as is to a separation facility where the individual rare earth oxides are separated out from the concentrate. If the mine has the appropriate technology and equipment, the concentrate can be separated into individual oxides onsite and then shipped to customers worldwide. Oxides and other rare earth chemicals are then processed by various methods into metals, powders, alloys, and other products before being used in semi-finished components (e.g., magnets, motors, catalysts) and, ultimately, in consumer products and military platforms.
Applications	Catalysts (Ce, La), glass (Ce), polishing (Ce), automotive catalysts (La, Ce, Nd), alloys (Ce, La, Nd), magnets (Nd, Sm, Dy, Pr), phosphors (Y, Tb, Eu), ceramics (Y), medical/pharmaceuticals (Y, Gd), and research. Some specific defense platforms include cerium oxide polishing powder for focal plane arrays; cerium oxide polishing powder for optical glass; lanthanum fluoride for fiber optics; lanthanum-based fluid cracking catalysts used to increase yield in jet fuels; lanthanum metal or alloy used in nickel-metal hydride (NiMH) batteries; neodymium and samarium for neodymium-iron-boron (Nd-Fe-B) and samarium-cobalt (Sm-Co) magnets, respectively; and yttrium and neodymium for neodymium: yttrium-aluminum-garnet (Nd:YAG) laser crystals.

Impact during a National Emergency	**Defense**	While substantial strides have been made in the development of the U.S. rare earth industrial base over the past few years, the United States still lacks capability along several nodes of the value chain, particularly in rare earth–based metals. The NDS Program is currently unaware of a disruption in the defense industrial base because of a lack of availability of rare earths, but an interruption could occur along several links of the supply chain during a national emergency. Specific applications that could be affected include heads-up displays and lasers for range finders and target designators.
	Essential Civilian	The impact would be widespread due to its use in consumer electronics, lighting, and green energy. Recycling is minimal and would currently not be able to significantly mitigate the risk.
Shortfall	**Yes**	Yes. There is a net shortfall of 37 metric tons for europium, a net shortfall of 820 metric tons for lanthanum, and a shortfall for high-purity yttrium (amount withheld).
Supply Risk	**Foreign Reliance; Single Point of Failure**	There is a single U.S. mine for rare earths and significant reliance on China for rare-earth-based materials.
Current Action	Legislative approval for acquisition of dysprosium and yttrium was obtained in the FY 2014 National Defense Authorization Act (NDAA).	
Recommended Action	Prepare legislative proposals and supply-chain analysis in FY 2015 for europium and lanthanum. Further study of scandium is recommended.	

Note on Rare Earth Data

The rare earth industry suffers from a basic lack of transparency requiring a “great deal of intuition and deduction” [Industrial Mineral Company of Australia (IMCOA), Bulletin #6 February, 2014] when estimating supply and demand. First, the supply chain of rare earths consists of a substantial quantity of partially processed chemicals, meaning a change in business plans can have a substantial effect on demand. Furthermore, improvements in efficiency of use (known as “thrifting”) over the past few years in response to soaring prices have further complicated demand estimation because while rare earths are found in a rising number of devices, the amounts used per device are falling. Thirdly, the impacts of illegal mining and smuggling are, by their very nature, unknown. Finally, the impact of technological change such as the adoption of hybrid electric vehicles, the development of LEDs, and the evolution of recycling activities can result in major swings in demand.

While there are numerous forms of rare earth materials, the data on rare earth supply and demand are typically presented as oxides or "oxide equivalent." Rare earth oxides, having undergone only one or two processing stages from the original ore, are considered raw materials. As such, rare earth oxide consumption is "buried in the supply chain" and appears nearly invisible in the final goods that use them. Furthermore, rare earth oxides are a small fraction of the price of the final good despite being critical (and, in many cases, essential) to the applications that use them. It should be emphasized that estimates of U.S. demand for rare earths as oxide underestimate the U.S. economy's reliance on rare earths, as illustrated by the United States' large import position in the finished products bearing rare earths.

Estimating supply is no less of a challenge. First, rare earth ore reserves are quoted by overall grade, not rare earth oxide (REO) metric tons delivered. In addition, annual mine plans are considered business proprietary information and therefore are rarely made public. Furthermore, the Chinese rare earth industry consists of many small players, many of whom operate illegally. Consolidation of the industry in China combined with the more vertically integrated operations of new producers in the United States and Australia should lead to more supply-side transparency. Finally, forecasting future supply is very difficult due to the many variables involved. Suffice to say that not all of the projects currently being planned will come to fruition.

The number of analysts attempting to estimate and forecast rare earth demand are too numerous to count. What is clear, however, is that no two analysts' figures ever agree. This unfortunate reality is the result of different estimation techniques, survey methods, and basic definitions of end-use sectors, categories, and data classification. Furthermore, it is simply impossible to independently verify data from the largest producing country, China. Finally, the trade statistics adhere to the harmonized system of tariffs (HTS) codes, which does not necessarily align with the way industry stakeholders categorize the data. As a general matter, the NDS Program relies heavily on three principal sources for its rare earth data: the U.S. Geological Survey (USGS), IMCOA/Curtin University, and Roskill. The NDS Program is constantly on the outlook for verifiable, consistent data.

The discussion on demand that follows will use data as assembled by NDS Program analysts and the USGS, with IMCOA/Curtin University data in parentheses.

Estimated Demand

World rare-earth-oxide demand totaled an estimated 94,335 metric tons (108,500 metric tons) in 2013, representing a 9.3 percent decline from the 2012 figure. At approximately 65,400 metric tons (68,000 metric tons), China led all consuming regions, accounting for nearly 70 percent of total world demand in 2013. Japan, with a demand of nearly 12,900 metric tons (15,000 metric tons), came in a distant second with 14 percent of world demand. The United States, at 8,500 metric tons (19,000 metric tons), accounted for 9 percent of global demand, while the rest of world accounted for 8.1 percent of the total, with 7,620 metric tons (6,500 metric tons).

Purchases of rare earth oxides have fallen dramatically over the past 2 years as consumers reacted to high prices in 2011 by working off inventories, thrifting, and substitution. Technological improvement was another factor behind the lower demand figures in 2013. To illustrate, the rapid adoption of the LED technology as well as new television and computer peripherals (which use fewer rare earths) has decimated the demand for phosphors used in these applications. To cite another example, more efficient use of materials has resulted in the smaller-sized magnets in hard disk drives and small motor actuators. Interestingly, the magnet end use was the only application to show year-over-year growth in 2013, advancing 5.4 percent over the 2012 figure. Rare-earth-oxide demand in every other end-use application fell between 6 percent and 13 percent in 2013.

In the end markets, battery alloys continued to be the top user of rare earths, with demand totaling nearly 26,000 metric tons (IMCOA does not split out battery alloys), accounting for 27 percent of total demand in 2013. This was followed closely by catalysts, with a demand totaling approximately 21,000 metric tons (22,000 metric tons), representing 22 percent of all demand. Rare earth oxides used in magnets was the third largest end use, with demand totaling 16,530 metric tons (23,000 metric tons), accounting for 18 percent of all demand. Phosphors were the fourth largest application, with rare earth oxide demand in this segment totaling 9,607 metric tons (7,000 metric tons) and accounting for 10 percent of total demand. The other applications, metallurgy, powders, and ceramics, had market shares ranging from 3 percent to 7 percent.

Cerium oxide was the largest among all individual rare earth oxides, with an apparent consumption totaling nearly 40,000 metric tons (39,850 metric tons) and accounting for 42 percent of the total demand. There is some debate over which rare earth oxide takes second place in terms of demand volume. Using NDS Program/USGS estimates, neodymium takes second place with a demand totaling 19,130 metric tons in 2013 (18,925 metric tons) for a market share of 20 percent. Lanthanum follows closely behind in third place with a demand totaling 18,600 metric tons (31,700 metric tons – second largest market per IMCOA) for a 19.7 percent market share. Using the IMCOA data, however, lanthanum is the second largest in terms of demand volume. The discrepancy among the rankings between lanthanum and neodymium is largely explained by the different estimates of rare earth usage in the United States' catalyst segment. NDS Program/USGS identified U.S. rare earth demand in the catalyst segment totaling about 2,700 metric tons, which accounted for 31 percent of all U.S. rare earth oxide demand. In contrast, IMCOA has the U.S. catalyst sector accounting for over 65 percent of U.S. rare earth oxide demand. Yttrium oxide demand was next in the pecking order, with a demand totaling 7,163 metric tons (7,585 metric tons) for a market share of 7.6 percent. This was followed closely by praseodymium, with a demand of nearly 6,000 metric tons (6,075 metric tons) for a 6.4 percent market share. The markets for the remaining oxides—Eu, Gd, Sm, Tb, Dy, Er, Ho, Tm, Yb, Lu—are small and highly specialized.

Supply

The discussion on supply that follows draws exclusively from data provided by IMCOA. It must be emphasized that these data are approximations only. Furthermore, full-year 2013 production figures in the United States would have likely been unknown to IMCOA at the time these estimates were made. As such, estimates of global totals for those elements (e.g., Ce, La, Nd/Pr, etc.) are likely to be overstated here.

Global production of rare earth oxides totaled an estimated 105,000 metric tons in 2013, representing a slight downturn from 2012 levels. The slide was the result of Chinese production curtailments and efforts by other producers to match production with demand as they attempted to ramp up their facilities. Downtime is common in the industrial commodities business as producers react to high inventories (both consumer and producer) and low prices by slowing production. Lower consumption by end users in response to high prices tugs against lower production by producers in response to low prices to create the ebb and flow of supply and demand. Inventory is one of the major linchpins in this cycle, and as these stocks wind down, buyers return to the market and producers ramp up production. In the rare earths business, however, inventory data are unavailable, so analysts rely on anecdotal information and price signals to infer the direction of inventories.

Production of the light rare earths (La, Ce, Pr, and Nd using the three group classification method) totaled 94,000 metric tons in 2013. Output of the medium rare earth oxides (Sm, Eu, and Gd) totaled 3,750 metric tons in 2013, while production of the heavy rare earth oxides (Tb, Dy, Er, and Y) totaled 7,250 metric tons.

Over the past 10 years, China dominated the production of rare earth oxides, accounting for up to 95 percent of global output. With the startup of new production in the United States and Australia, however, China's dominance in rare earth oxide production (particularly in the light rare earths) has begun to erode. China still commands the lion's share of medium and heavy rare earth oxide production with a market share of 93 percent and 99 percent, respectively, in those groups. China is also still a major producer of the light rare earths, accounting for 84 percent of global production. Nevertheless, the increased diversity of supply over the past few years is a healthy development in the rare earth supply chain.

Going forward, rare earth supplies are forecast to increase as production in the United States and Australia reaches full production and new facilities come on line. Chinese production is also expected to grow albeit at a slower rate than the rest of the world owing to the mature nature of their rare earth mining sector and efforts to consolidate the industry from hundreds of producers to just eight. According to research firm Technology Metals Research, as of March 7, 2014, there were 57 rare earth mineral resources at an "advanced" stage associated with 51 advanced rare earth projects involving 49 different companies and located in 34 different regions within 16 different countries. The search for new rare earth resources is pervasive and global. Resource grade, project economics, access to financing and infrastructure, and the evolution of rare earth prices are just a few of the variables that will dictate who succeeds and who fails. According to IMCOA, global rare-earth-oxide production is forecast to total an estimated 175,000 metric tons by 2017, for a gain of 65,000 metric tons over the 2013 estimate.

Individual Rare Earth Element Tables

Cerium

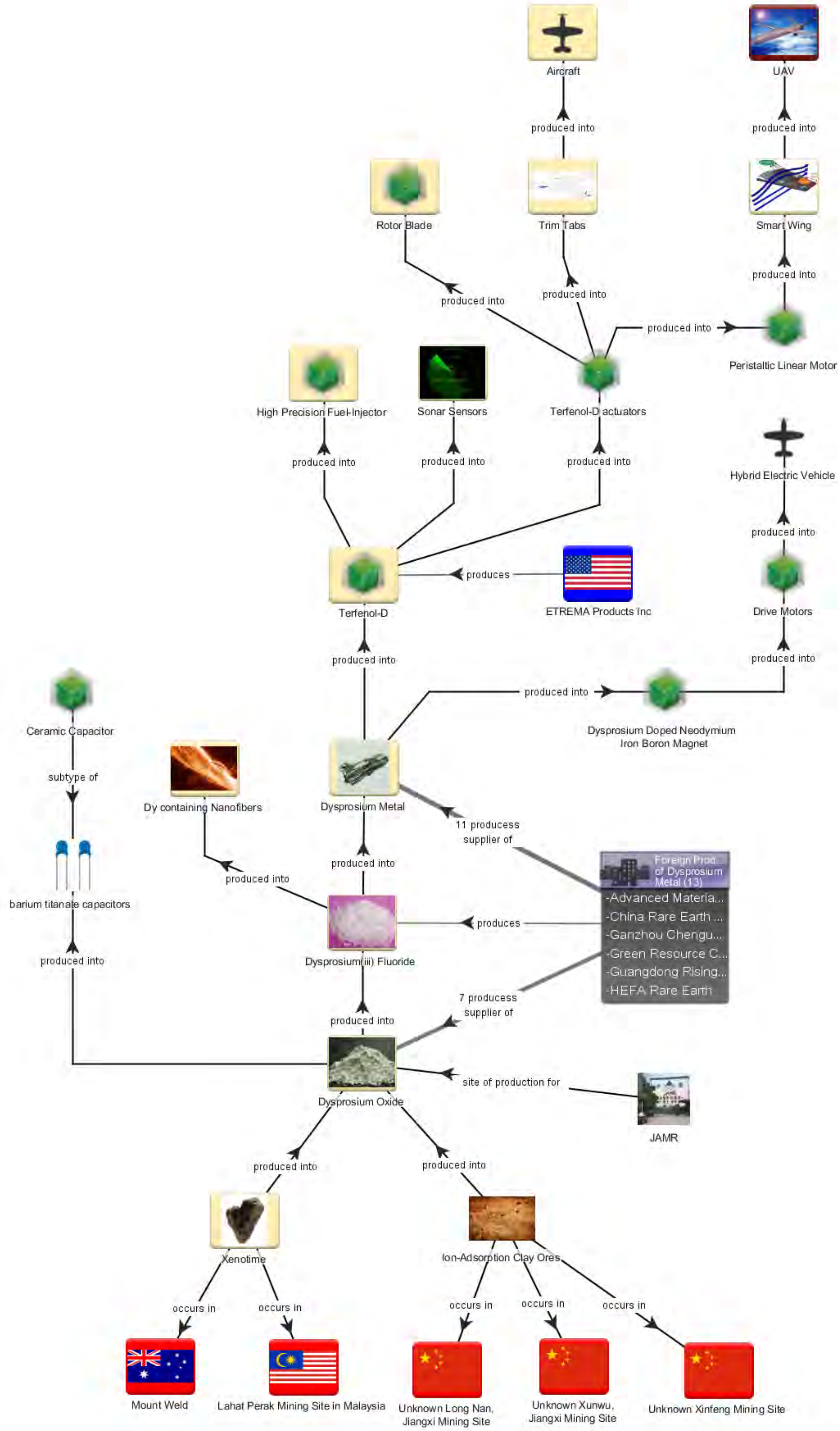
Description	Cerium (Ce) is a light rare earth element generally used in oxide form because it is toxic and reactive in metal form. There are domestic reserves of light rare earth elements, and cerium is the most abundant rare earth element.	
Applications	Additive and polishing abrasive for glass manufacturing, including for optical lenses and wafers, catalyst for automobiles and chemical industry, paint, phosphors for display screens, water treatment.	
Impact during a National Emergency	**Defense**	Impact likely limited due to availability of substitutes.
	Essential Civilian	Limited impact due to availability of substitutes.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risk	**Single Point of Failure**	Although previously entirely dependent on imports for cerium supply, the United States currently has one domestic producer.
Current Actions	All rare earth elements are carefully monitored for potential changes to supply.	
Recommended Action	Continue monitoring efforts.	

Dysprosium

Description	Dysprosium (Dy) is a heavy rare earth element and metal with magnetic properties. Heavy rare earth elements are generally rarer than the light ones.	
Applications	Used mainly in neodymium-iron-boron-based permanent magnets where it makes up generally about 0.8 to 1.2 percent of the magnet weight but can be up to 11 percent by weight. Neodymium-iron-boron magnets are then used in end products such as computer hard disk drives, magnetic resonance imaging (MRI), automotive motors, wind turbines, and loudspeakers. Also used in phosphors and some lasers.	
Impact during a National Emergency	**Defense**	Substitution difficult because of high performance desired for defense. High dependence in commercial off-the-shelf (COTS) parts.
	Essential Civilian	Neodymium-iron-boron magnets have better magnetic properties than alternative materials. However, dysprosium content has successfully been reduced without significant loss of performance for many commercial applications.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risk	**Foreign Reliance**	Although dependent on imports, a U.S.-based company does produce it. Significant supply chain steps for dysprosium-containing permanent magnet production are still entirely OCONUS.
Current Actions	Approved for stockpiling in the 2014 NDAA, section 1412.	
Recommended Action	Continue approved acquisition of 0.5 metric tons.	

Supply Chain

As one of the current materials with acquisition authority, ORNL and the NDS Program have prioritized documenting the materials flow diagram for dysprosium, the core of which is shown as follows.



Aircraft
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Smart Wing
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High Precision Fuel-Injector
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-Ganzhou Chengu...
-Green Resource C...
-Guangdong Rising...
-HEFA Rare Earth
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Dysprosium Oxide
JAMR
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Xenotime
Ion-Adsorption Clay Ores
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occurs in
occurs in
Mount Weld
Lahat Perak Mining Site in Malaysia
Unknown Long Nan, Jiangxi Mining Site
Unknown Xunwu, Jiangxi Mining Site
Unknown Xinfeng Mining Site

Erbium

Description	Erbium (Er) is a heavy rare earth element and bright silver metal. Heavy rare earth elements are generally rarer than the light ones.	
Applications	Used in lasers, fiber optics, pink color for glass and enamel, cryocooler, alloy additive.	
Impact during a National Emergency	**Defense**	Data are very limited on erbium's potential impact on defense.
	Essential Civilian	Erbium uses are limited and somewhat substitutable in most applications.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risk	**Foreign Reliance**	Although entirely dependent on imports for erbium supply, a U.S.-based company does produce it. However, sourcing and processing occur at foreign facilities.
Current Actions	All rare earth elements are carefully monitored for potential changes to supply.	
Recommended Action	Improve quantification of erbium use in defense, where its use in very small amounts makes it challenging to identify.	

Europium

Description	Europium (Eu) is a medium/heavy rare earth element and hard non-toxic silver metal. Heavy rare earth elements are generally rarer than the light ones.	
Applications	Used mostly in phosphors, which are in turn used in TV and computer screens, compact fluorescent lighting, LEDs, and sensors. Also used in small quantities for ceramics, specialty glass additives, and lasers.	
Impact during a National Emergency	**Defense**	Limited and specialized uses throughout the military in applications such as phosphors (red, blue, white) and lasers.
	Essential Civilian	Critical for increasing the energy efficiency of lighting (e.g., white LEDs) and visual displays.
Shortfall	**Yes**	There is a net shortfall equivalent to 37 metric tons oxide.
Supply Risk	**Foreign Reliance**	Although previously entirely dependent on imports for europium supply, the United States currently has some domestic production. Some processing occurs at foreign facilities.
Current Actions	All rare earth elements are carefully monitored for potential changes to supply.	
Recommended Action	Recommend stockpiling 37 metric tons of europium. Further study to improve quantification of europium use in defense, where its use in very small amounts makes it challenging to identify.	

Gadolinium

Description	Gadolinium (Gd) is a medium/heavy rare earth element and silvery-white ductile metal. Heavy rare earth elements are generally rarer than the light ones.	
Applications	Used in very small quantities in automotive and fuel cracking catalysis, phosphors, magnets, microwave applications, and other alloys. Also used in medicine for MRI.	
Impact during a National Emergency	**Defense**	Limited and specialized uses throughout the military in applications such magnets, lasers, radar, and avionics display.
	Essential Civilian	It is difficult to assess criticality, as small amounts are used in many civilian applications, including medical, automotive, and electronics.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risk	**Foreign Reliance**	Although previously dependent on imports for all of the gadolinium supply, a U.S.-based company now mines and produces it. Some processing steps occur at foreign facilities.
Current Actions	All rare earth elements are carefully monitored for potential changes to supply.	
Recommended Action	Improve quantification of gadolinium use in defense, where its use in very small amounts makes it challenging to identify.	

Holmium

Description	Holmium (Ho) is a heavy rare earth element and metal having a strong magnetic moment. Heavy rare earth elements are generally rarer than the light ones.	
Applications	Used in magnets, glass, and lasers.	
Impact during a National Emergency	**Defense**	Data on holmium's potential impact on defense are very limited. Use is believed to be small.
	Essential Civilian	Uses are limited, but substitution comes with some loss of performance.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risk	**Foreign Reliance**	Although entirely dependent on imports for holmium supply, a U.S.-based company does produce it. However, sourcing and processing occur at foreign facilities.
Current Actions	All rare earth elements are carefully monitored for potential changes to supply.	
Recommended Action	Improve quantification of holmium use in defense, where its use in very small amounts makes it challenging to identify.	

Lanthanum

Description	Lanthanum (La) is a soft metal and the lowest molecular weight element in the lanthanide series. The United States and China have the world's largest known resources. Most rare earth ores contain large fractions of lanthanum (up to a third). It oxidizes quickly in air, and most applications use it in oxide form.	
Applications	Metal alloys for nickel metal hydride batteries, fiber-optical communication systems, heat-resistant superalloys, ferritic and samarium-cobalt magnets, steel alloys, ceramic capacitors, semiconductors, and other components for LCDs and electronics, glass manufacturing, doping agent for camera and telescope lenses.	
Impact during a National Emergency	**Defense**	Potentially critical due to lack of substitution options for applications such as heat-resistant superalloys, magnets, high-strength 300 M steel landing gear struts, and IR-absorbing glass for night-vision goggles.
	Essential Civilian	In addition to having minimal recycling (<1 percent), substitutes are not available for most applications except batteries, where the improved performance of lithium-ion batteries has led to significant substitution.
Shortfall	**Yes**	There is a net shortfall of 820 metric tons oxide basis.
Supply Risk	**Single Point of Failure**	Previously, the United States was entirely dependent on imports for lanthanum supply. The United States currently has one domestic producer.
Current Actions	All rare earth elements are carefully monitored for potential changes to supply.	
Recommended Action	Acquire 820 metric tons oxide basis. Further study defense uses and forms of lanthanum.	

Lutetium

Description	Lutetium (Lu) is a heavy rare earth element and hard metal that is very difficult to separate and process and is hence very expensive. Heavy rare earth elements are generally rarer than the light ones.	
Applications	Used in lasers, phosphors, high-refractive-index optical lenses, catalysis.	
Impact during a National Emergency	**Defense**	Data are very limited on lutetium's potential impact on defense. Use is very small and limited.
	Essential Civilian	Uses are limited to those applications where substitution is very difficult.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risk	**Foreign Reliance**	Entirely dependent on imports for lutetium supply.
Current Actions	All rare earth elements are carefully monitored for potential changes to supply.	
Recommended Action	Improve quantification of lutetium use in defense, where its use in very small amounts makes it challenging to identify.	

Neodymium

Description	Neodymium (Nd) is a light rare earth element and magnetic metal. Available in larger concentrations in rare earth ores as light rare earth elements are generally less scarce than the heavy ones. A component of rare earth mischmetal along with lanthanum, cerium, and neodymium.	
Applications	Neodymium-iron-boron magnets for electronics, automobiles, MRI machines, nickel metal hydride batteries, cryocoolers, CRTs, lasers, minor alloying element for iron and steel alloys.	
Impact during a National Emergency	**Defense**	Neodymium-iron-boron permanent magnets are critical to defense as they are used in electric motors for a variety of applications. Substitution and thrifting are limited.
	Essential Civilian	Considered essential for clean energy technologies such as wind turbines and hybrid and electric vehicles. Recycling and substitution are limited and generally result in loss of performance.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risk	**Single Point of Failure**	Although previously entirely dependent on imports for supply, the United States currently has some domestic production.
Current Actions	All rare earth elements are carefully monitored for potential changes to supply.	
Recommended Action	Continue monitoring efforts.	

Praseodymium

<table>
<tr><td>Description</td><td colspan="2">Praseodymium (Pr) is a light rare earth element and soft, ductile metal. Available in larger concentrations in rare earth ores as light rare earth elements are generally less scarce than the heavy ones. A component of rare earth mischmetal along with lanthanum, cerium, and neodymium.</td></tr>
<tr><td>Applications</td><td colspan="2">Used as a minor alloy for the casting of steel and iron, in nickel metal hydride batteries, in neodymium-iron-boron magnets, optical lenses, optical filters, coatings, ceramic capacitors, semiconductors, and other components for LCD and electronics, alloyed with magnesium in aircraft engines.</td></tr>
<tr><td rowspan="2">Impact during a National Emergency</td><td>Defense</td><td>Praseodymium is used with neodymium in neodymium-iron-boron permanent magnets, which are critical to defense. Substitution is limited and tends to be only with other rare earth elements.</td></tr>
<tr><td>Essential Civilian</td><td>Recycling is limited, and substitution is possible but generally results in loss of performance.</td></tr>
<tr><td>Shortfall</td><td>No</td><td>Per the 2015 NDS Program Study.</td></tr>
<tr><td>Supply Risk</td><td>Single Point of Failure</td><td>Although previously entirely dependent on imports, the United States currently has some domestic production.</td></tr>
<tr><td>Current Actions</td><td colspan="2">All rare earth elements are carefully monitored for potential changes to supply.</td></tr>
<tr><td>Recommended Action</td><td colspan="2">Continue monitoring efforts.</td></tr>
</table>

Samarium

Description	Samarium (Sm) is a light/medium rare earth element and magnetic metal. Available in small (0.8–2.8 percent approximately) concentrations in rare earth ores. May be a minor component of some rare earth mischmetals that are available on the market.	
Applications	Samarium-cobalt permanent magnet used in electronics, automobiles, and other transport vehicles; IR absorption glass; optical glass; capacitor for microwave frequencies.	
Impact during a National Emergency	**Defense**	Limited and specialized uses throughout the military.
	Essential Civilian	Somewhat substitutable by other rare earth elements.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risk	**Single Point of Failure**	Although previously entirely dependent on imports for supply, the United States currently has some domestic production.
Current Actions	All rare earth elements are carefully monitored for potential changes to supply.	
Recommended Action	Continue monitoring efforts.	

Scandium

Description	Scandium (Sc) is a transition metal that is often grouped with the rare earth elements. It is generally found as a by-product of other metals and has a very small market. Can be alloyed with aluminum to produce aluminum-scandium alloys, which are lightweight, have high-temperature stability, higher strength but also higher cost.	
Applications	High-intensity mercury-vapor lamps, lasers, and solid oxide fuel cells. Aluminum-scandium has specialty applications such as in sports gear (baseball bats) and some aerospace and naval applications. Scandium applications assessed for this report also include a number of important defense requirements. See details in the Proprietary section.	
Impact during a National Emergency	**Defense**	Limited, however aluminum-scandium alloys do provide a combination of lightweight and high strength that is difficult to substitute with alternatives.
	Essential Civilian	Most civilian applications can use alternatives to scandium. Substitution is harder for solid oxide fuel cells as alternatives require higher operating temperatures.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risk	**Significant Foreign Dependence and Limited to No Domestic Capacity**	Production of scandium oxide is limited to a few foreign countries, namely, China, Kazakhstan, Russia, and Ukraine. Domestic production capabilities and capacities for downstream scandium-containing materials are often limited and in some cases do not exist.
Current Actions	All rare earth elements are carefully monitored for potential changes to supply.	
Recommended Action	Further study recommended to quantify essential civilian and defense demand for scandium.	

Terbium

Description	Terbium (Tb) is a heavy rare earth element and silver-gray ductile metal. Heavy rare earth elements are generally rarer than the light ones.	
Applications	Used in phosphors (green) for displays, high-temperature fuel cells (solid oxide fuel cell), lasers, and magnetostrictive alloys for solid-state transducers and actuators.	
Impact during a National Emergency	**Defense**	Data is very limited on terbium's potential impact on defense.
	Essential Civilian	Terbium uses are limited and somewhat substitutable by other rare earth elements, although with some loss of performance.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risk	**Foreign Reliance**	Although dependent on imports for terbium supply, a U.S.-based company does produce it. It is important to note that this company also operates facilities outside the OCONUS. Some processing steps are still occurring entirely OCONUS.
Current Actions	All rare earth elements are carefully monitored for potential changes to supply.	
Recommended Action	Improve quantification of terbium use in defense, where its use in very small amounts makes it challenging to identify.	

Thulium

Description	Thulium (Tm) is a heavy rare earth metal and second-rarest element after promethium.	
Applications	Uses are very limited as it is very expensive and rare. Used in portable x-ray devices and research and can be used in some lasers.	
Impact during a National Emergency	**Defense**	Data are very limited on thulium's potential impact on defense.
	Essential Civilian	Limited impact due to limited use.
Shortfall	**No**	Per the 2015 NDS Program Study.
Supply Risk	**Foreign Reliance**	Entirely dependent on imports for thulium supply.
Current Actions	All rare earth elements are carefully monitored for potential changes to supply.	
Recommended Action	Improve quantification of thulium use in defense, where its use in very small amounts makes it challenging to identify.	

Ytterbium

<table>
<tr><td>Description</td><td colspan="2">Ytterbium (Yb) is a heavy rare earth element and malleable silvery metal. Heavy rare earth elements are generally rarer than the light ones.</td></tr>
<tr><td>Applications</td><td colspan="2">Used in optical glasses, crystals and ceramics, in some stainless steels and super alloys. Ytterbium lasers can be used to drill into diamonds, for micromachining, and to mark products. Known defense applications include satellite-based infrared (SBIR) sensors (surveillance and missile launch detection), thin, antireflective film on optical components such as lenses, dopant in solid-state lasers, fiber-optic amplifiers, and night-vision coatings.</td></tr>
<tr><td rowspan="2">Impact during a National Emergency</td><td>Defense</td><td>Data are very limited on ytterbium’s potential impact on defense. Use is believed to be small.</td></tr>
<tr><td>Essential Civilian</td><td>Uses are limited, but substitution comes with some loss of performance.</td></tr>
<tr><td>Shortfall</td><td>No</td><td>Per the 2015 NDS Program Study.</td></tr>
<tr><td>Supply Risk</td><td>Foreign Reliance</td><td>Entirely dependent on imports for ytterbium supply, although small concentrations are found in one U.S. mine project and a Canadian and an Australian mine project.</td></tr>
<tr><td>Current Actions</td><td colspan="2">All rare earth elements are carefully monitored for potential changes to supply.</td></tr>
<tr><td>Recommended Action</td><td colspan="2">Further study of ytterbium uses for defense and need for stockpiling are recommended in this report.</td></tr>
</table>

Yttrium

Description	Yttrium (Y) is a soft metal that is often grouped with the rare earth elements in part because it has similar properties. Yttrium occurs with most rare earths deposits and is recovered mainly from monazite sands. It is initially produced as an oxide.	
Applications	Pigment and stabilizer in ceramics, high-temperature superconductors, phosphors for display screens, lasers, deoxidizer for vanadium and other nonferrous metals, catalyst in chemical industry and automobiles, solid electrolytes for fuel cells, refractory material. See details for yttrium oxide in the Proprietary section.	
Impact during a National Emergency	**Defense**	There are no known substitutes immediately available for yttrium in certain applications.
	Essential Civilian	Limited although it is barely recycled and only somewhat substitutable except for some ceramics.
Shortfall	**No**	No yttrium net shortfall. Yttrium oxide details withheld.
Supply Risk	**Foreign Reliance**	
Current Actions	Acquisition of yttrium oxide was approved in the 2014 NDAA.	
Recommended Action	The NDS Program continues to assess DoD requirements. Yttrium oxide details are in the Proprietary section.	

Appendix 6b. Proprietary or For Official Use Only (FOUO) Material Summary Tables

This section contains Proprietary or For Official Use Only information.

Appendix 7
Acronyms

AC	Alternate Case
AMC	U.S. Army Material Command
AP	ammonium perchlorate
B4C	boron carbide
BCA	Business Case Analysis
BFA	brown fused alumina
BLM	Bureau of Land Management
BT	1,2,4-butanetriol
BTTN	1,2,4-butanetriol trinitrate
CA	challenge area
CaF_2	calcium fluoride
CAGR	compound annual growth rate
CAWG	Civilian Agency Working Group
CCMD	Combatant Command
CEA	Council of Economic Advisors
CIGS	solar thin film photovoltaics
CONOPS	Concept of Operations
COTS	commercial off the shelf
CPE	chlorinated polyethylene
CRT	cathode ray tube
CSM	chlorosulfonated polyethylene
CTWG	Critical Technologies Working Group

CZ	Czochralski
CZT	cadmium-zinc-telluride
DoC	U.S. Department of Commerce
DoD	U.S. Department of Defense
DoE	U.S. Department of Energy
DPAS	Defense Priorities and Allocation System
DRC	Democratic Republic of Congo
EFP	explosively formed penetrator
EMD	electrolytic manganese dioxide
EMM	electrolytic manganese metal
EOC	Emergency Operating Capacity
EPA	U.S. Environmental Protection Agency
ETF	electronically traded fund
FFRDC	Federally Funded Research and Development Center
FLIR	forward looking infrared
FORCEMOB	Force Mobilization Model
FPDs	flat panel displays
FSA	fluorosilicic acid
FY	Fiscal Year
FYDP	Future Years Defense Program
G&S	U.S. goods and service
GaAs	gallium arsenide
GaN	gallium nitride
GDP	Gross Domestic Product
GPS	Global Positioning System

GRG	general rubber goods
HBT	hetero-junction bipolar transistor
HF	hydrofluoric acid
HM	high modulus
HMX	cyclotetramethylene-tetranitramine
HS	high strength
HTPB	hydroxyl-terminated polybutadiene
HVPE	hydride vapor phase epitaxy
IC	Intelligence Community
ICS	Integrated Security Construct
ICCARM	Integrated Cross-Capability Assessment and Risk Management
IDA	Institute for Defense Analysis
IHE	Insensitive High Explosive
ILIAD	Inter-industry Large-scale Integrated and Dynamic Model
ILZSG	International Lead/Zinc Study Group
IM	intermediate modulus
IMCOA	Industrial Mineral Company of Australia
INFORUM	Inter-industry Forecasting Project
InP	indium phosphide
IR	infrared
IRAMM	Integrated Risk Assessment and Management Model
IRSG	International Rubber Study Group
ISCs	Integrated Security Constructs
ISR	intelligence, surveillance, and reconnaissance
ITRI	International Tin Research Institute

IW	Irregular Warfare
JMTC-RIA	Rock Island Arsenal Joint Manufacturing & Technology Center
ksi	kilo square inches
LCD	liquid crystal display
LEC	liquid-encapsulated Czochralski
LEDs	light-emitting diodes
LIFT	Long-term Inter-industry Forecasting Tool
LME	London Metal Exchange
LPE	liquid-phase epitaxy
ManTech	U.S. Army Manufacturing Technology Program
MBE	molecular beam epitaxy
MCOs	Major Combat Operations
MCR	material consumption ratio
MDA	Missile Defense Agency
MIBP	Office of Manufacturing and Industrial Base Policy
MMICs	monolithic microwave integrated circuits
MOCVD	metal organic chemical vapor deposition
MON	mixed oxide of nitrogen
MOU	Memorandum of Understanding
MRI	magnetic resonance imaging
MT	metric tons
NASA	National Aeronautics and Space Administration
NDAA	National Defense Authorization Act
NDS Program	National Defense Stockpile, managed by the Defense Logistics Agency

	Strategic Materials
NiCd	nickel cadmium
NiMH	nickel–metal hydride
NNSA	National Nuclear Security Administration
NSS	National Security Space
NTO	nitrogen tetroxide
NTO	nitrotriazolone
OCONUS	outside the contiguous United States
OEM	original equipment manufacturer
OSD JDS	Office of the Secretary of Defense Joint Data Support
OSD	Office of the Secretary of Defense
OSD/CAPE	Office of the Secretary of Defense/Cost Analysis and Program Evaluation
OUSD AT&L	Office of the Undersecretary of Defense for Acquisition, Technology and Logistics
PA	power amplifier
PAN	polyacrylonitrile
PGM	platinum group metals
PVC	polyvinyl chloride
RAMF-SM	Risk Assessment and Mitigation Framework for Strategic Materials
RDX	cyclotrimethylene-trinitramine
SBIR	satellite-based infrared
SF6	sulfur hexafluoride
SG	standard grade
SIBC	Space Industrial Base Council
SiC	silicon carbide

SM	Strategic Materials
SMART	Strategic Material Analysis & Reporting Topography
SMC	Space Missile Command
SME	Subject Matter Expert
SOSA	Security of Supply Arrangement
SRM	solid rocket motors
SrSO4	celestite
SSM	Stockpile Sizing Module
ST	short ton
T-Fund	National Defense Stockpile Transaction Fund
TATB	triamino-trinitrobenzene
TCB	1,3,5 trichlorobenzene
TIC	Tantalum-Niobium International Study Center
TPPL	thin-plate pure lead
UAVs	unmanned aerial vehicles
UCAV	unmanned combat air vehicle
UHF	ultra high frequency
UHMWPE	ultra high molecular weight polyethylene
USAF	U.S. Air Force
USGS	United States Geological Survey
USN	U.S. Navy
VGF	vertical-grade freeze
VIM	vacuum induction melt
VPE	vapor phase epitaxy
W	withheld

WFA	white fused alumina
WMD	Weapons of Mass Destruction
WW I	World War I